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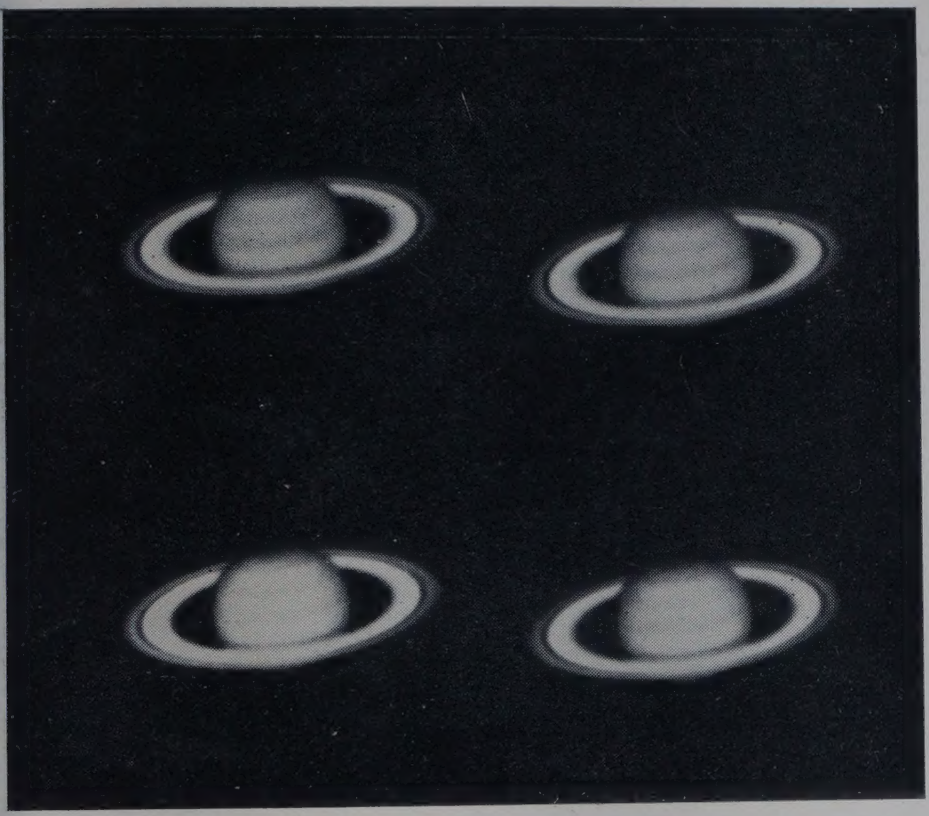

R.A.S. No. 245. Saturn, 1911, Nov. 19. E. E. Barnard.

R.A.S. 291. Eclipse, 1919 May 29. Sobral, Brazil. R.O.G. Expd. Ap. 4 in., *f.l.* 228 in. Exp. 28s.

[*Frontispiece.*

AN EASY OUTLINE OF ASTRONOMY

BY
M. DAVIDSON, D.Sc., F.R.A.S.

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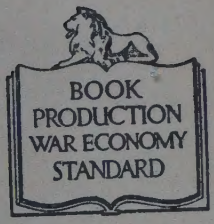

THIS BOOK IS PRODUCED IN COMPLETE
CONFORMITY WITH THE
AUTHORISED ECONOMY STANDARDS

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PREFACE

is work is intended for those who have no knowledge astronomy, and has been designed to present the bject in the simplest language. For this reason chnical terms and mathematical formulae have been oided, as far as possible, and it is hoped that this mple outline will prove a stepping-stone to the more ious study of astronomy. The black-out has been sponsible for arousing a considerable amount of terest in the heavenly bodies, and those who had given thought to the wonders of the heavens in pre-war ys are now finding how fascinating the subject can be. The present work is confined to a description of the ovements, dimensions, masses, and composition of the avenly bodies, but in its limited scope it has been mpossible to deal with the identification of the constel-ions and stars. Those who wish to pursue this side the subject will find a short list of star charts at the d of the book, and any of these will enable them, with little perseverance, to recognize the chief constellations nd stars.

I wish to express my thanks to Sir Harold S. Jones, e Astronomer Royal, for permission to reproduce the notograph of the eclipse of the sun on May 29, 1919. am also very grateful to Mr. F. J. Sellers, Editor of *he Journal of the British Astronomical Association*, for s assistance with the preparation of the diagrams. inally, I wish to record my gratitude to the publishers, nd especially to Mr. A. G. Whyte, for their interest in e preparation of the book and for numerous sugges-ons regarding its presentation.

Just before revising the text for the third impression y work *From Atoms to Stars* (Hutchinson's Scientific nd Technical Publications) appeared. This deals uch more fully with many of the points merely eferred to in the present volume.

M. DAVIDSON.

August, 1943.

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INTRODUCTION

STRONOMY is the oldest of all sciences, and has rightly en called the Queen of the Sciences. It is a subject at has attracted the attention of men from the earliest nes, though there are no records which tell us of the wn of astronomy. We know for certain that the early habitants of the earth not only regarded the heavenly dies with wonder and awe; they even built temples in eir honour and worshipped a number of them as deities. Those who make no claim to be astronomers are aware the apparent daily motion of the sun across the heavens m east to west, and it is only necessary to observe the rs for about an hour any night to see that they also are in this apparent motion. Like the sun, stars are en rising in the east and slowly mounting higher above e horizon, while others near the west are observed to ove nearer and nearer to the horizon and finally to sappear. It is not surprising that people once believed e earth was the centre of the universe and that all the avenly bodies moved round it, completing their course 24 hours. We know now that the apparent motion of e stars is due to the spinning motion of the earth, hich is explained more fully in the first chapter. It is markable that there was a time when people who dared suggest that the earth moved might lose their lives. is just 310 years ago since Galileo was condemned for aintaining that the earth moved, and he saved his life ly by renouncing his "errors and heresies." Fortun-ely we now live in more tolerant days when there is thing to prevent men of science from advocating their ews even if they are erroneous. In spite of the ormous progress in astronomy, some people still lieve that the earth is flat and that the heavenly bodies e all moving round it. Such people can become very esome if one tries to convince them of their errors. me time ago one of them wrote to me and advanced a mber of "arguments" disproving the motion of the

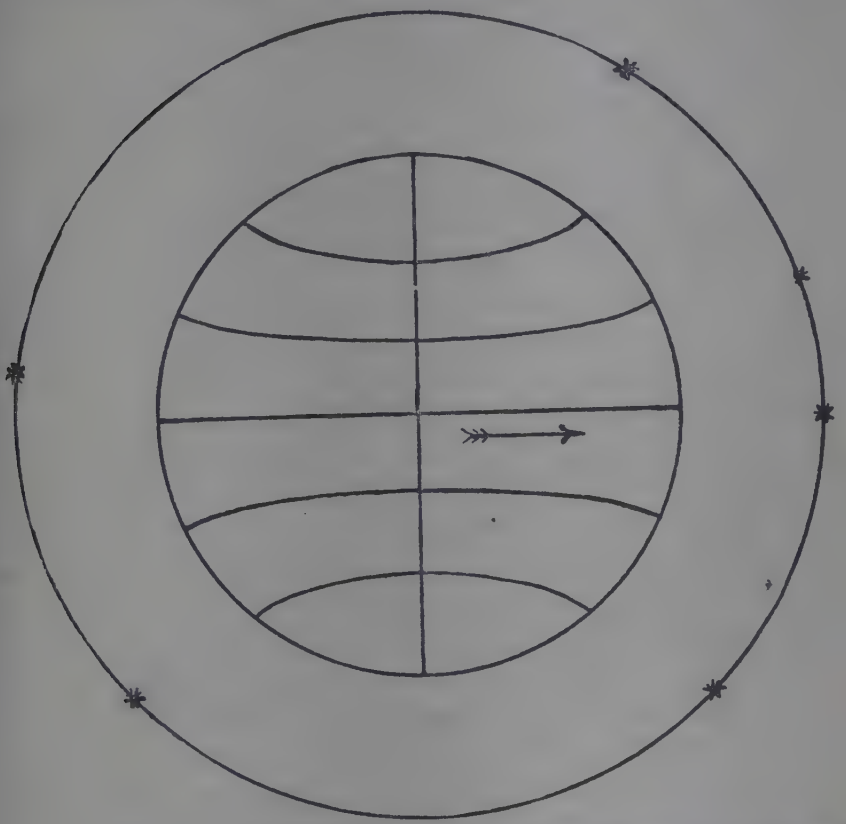
earth. I tried to deal with his difficulties, but without any success, and finally he wrote a very rude letter, in which he accused me of being an Atheist. As evidence of this he quoted Psalm civ, 5: " Who laid the foundations of the earth, that it should not be moved for ever." The Royal Observatory, Greenwich, still receives communications from flat-earthers who supply " proofs " that the earth is fixed in space and that all the heavenly bodies are moving round it as centre.

You may have noticed at a railway station that when your train is moving out of the station, another train near by seems to be moving in the opposite direction. In fact, you may be uncertain for a time whether your train is moving or whether it is the other train that is in motion. It is the same with the earth and the stars. We think that the stars are moving from east to west, but things would appear the same if the stars were standing still and the earth was turning from west to east. There are certain experiments which prove conclusively that the earth is turning in this way, but you must wait until you have read more advanced text-books on astronomy before you can understand these experiments.

The following argument will prove convincing in the meantime. If the heavenly bodies are all moving round the earth as a centre, then those which are far away must have enormous speeds compared with those which are nearer. Now we know that the stars are situated at different distances from the earth (this point will be dealt with later), and hence we must conclude that their speeds are so adjusted that those which are far off must move millions of times faster than those which are nearest to us, in order that they may all complete their journeys in the same time. How much simpler it is to accept the fact that the earth is spinning round once in a day and that the motions of the heavenly bodies are only apparent, and are caused by the motion of the earth in the opposite direction.

When you look at the sky on a clear night you may see the moon and perhaps two or three planets, but by far the most numerous of the heavenly bodies which are visible are the stars. It is important that you should

ow the distinction between a star and a planet, not
ly by their appearances, but also by the great difference
their condition. The best way to do so is to remember
at the sun is a typical star and the earth a typical planet.
tronomers can understand very much better what they
serve on the stars if they first study the sun. They can



IG. 1.—As the earth rotates in the direction shown by the arrow the heavenly bodies appear to move in the opposite direction.

lso understand the planets better when they have made careful study of the earth—not only of its ordinary eatures, such as mountains, oceans, seas, etc., but also of s atmosphere, and even of the conditions far down in s interior. When you look at a star, remember that ou are looking at a body which is similar to the sun. t is intensely hot and bright, and because of its bright-ess we can see it. Although many of the stars are very nuch hotter than the sun, we derive no advantage from heir heat, because of their enormous distances in

comparison with the distance of the sun. The neare star is about 270 thousand times as far away from th earth as the sun is.

A useful comparison can be obtained as follows Imagine that the sun is situated at a distance of 10 fe from the earth; a model on the same scale would requi a distance of 510 miles to represent the position of th nearest star. When we come to deal with the planets w are observing bodies which are comparatively close. O the same scale which places the sun 10 feet away from th earth, the planet Pluto, which is the farthest away of a the planets, would be about 400 feet away. When we g beyond Pluto we reach empty space for an enormou distance—actually 26 million million miles—before w reach the nearest star. The average distances betwee the stars can be taken as something similar to thi distance from the earth to the nearest star.

These comparisons will show you that our earth i really a very small speck in the universe. It is just on of nine planets which move round the sun, and the sun itself is merely an ordinary star out of millions of millions It is possible that many of these stars have planets moving round them as the planets which we know move round the sun, but we cannot be certain about this.* If there are such planets, some of them have probably got life on them, just as a few of the planets belonging to our sun may have life. We know that there are two of them, besides the earth, on which the conditions are suitable for life in some form, though of course it is most unlikely that the highest form of life on them resembles human beings. Something will be said in a later chapter on this point, and we can leave it for the present.

Before giving a more detailed description of the stars and each planet, it is advisable that the reader should

* While reading the proofs it was announced that a planetary companion to the double star 61 Cygni had been discovered. The body is estimated to have a mass sixteen times that of Jupiter, and hence is large for a planet. It is the first discovery of a planetary body outside the solar system. This new planet has not been seen, as it is too small and faint to be observed even in the most powerful telescope. Its presence is known from its disturbance to the motion of the components of the double star 61 Cygni.

ain a general view of the system of stars to which we ong. At any place it is possible to see about 3,000 rs with the naked eye, and as we can see only half the al number of stars at any place, the number which is hin the range of the naked eye is about 6,000. Of ırse this is only a very minute fraction of the number of rs which can be observed with a moderate-sized escope or which is within the range of the astronomer's otographic equipment. All the stars which you see ong to what is known as the *Galaxy*, which contains ything from 30 thousand million stars to twice that mber (up to the present the number has not been ermined with great accuracy). You will see that 00 stars out of this enormous number is very small; vertheless these 6,000 can be taken as typical of those the whole galaxy. The Milky Way is another name the galaxy,* and you have probably seen it on a ar night as a luminous girdle around the heavens. nen you remember the number of stars in it, it is not prising that it appears luminous. Of course they are far off to be separately visible to the naked eye, but combined light of these millions of stars produces faint glow.

In some places you may have noticed rifts in the girdle. ese are not due to the absence of stars, but are caused dust-clouds which cut off the light from us, just as a dstorm cuts off the light of the sun, or a cloud makes sun look darker. The galaxy is only one of hundreds thousands of systems of stars which are separated m one another by vast distances, but at present we ll confine our attention to our own galaxy. A model this is shown in Fig. 11, Chapter VIII. It is seen from s that the galaxy is bun-shaped, its thickness at the ntre being about one-sixth of its diameter *AB*. The ckness diminishes rapidly from the centre to the tside of the system, so that, taken on the whole, the

* Galaxy and Milky Way are often used to mean our entire tem of stars, but strictly speaking "Milky Way" should be tricted to the portion of the galaxy which shows as a white dle across the heavens. The stars on either side of this girdle ong to our galaxy, but are not considered to form part of the lky Way.

galaxy has a very flattened appearance. Among the 30 thousand million stars in the galaxy there is one which is important for our purpose, because from it we derive our heat and light, and without it all life on earth would perish. This star is called the sun. It is not situated at the centre of the galaxy, as astronomers once believed, but is very much to one side, and is marked X in the diagram.

If there are astronomers on planets belonging to any of the other stars, they would be able to see the sun with or without their telescopes, and they would probably find out that it was not a very conspicuous star, being very much fainter and smaller than some, though brighter and larger than many others. None of the planets belonging to the sun would be visible even with the most powerful telescopes, and the astronomers might speculate on the possibility of planets existing in association with the sun, just as astronomers on the earth speculate on the possibility of planets being associated with the various stars. Our most powerful telescopes fail to detect such planets, and probably will always fail to detect them, even if they are much larger than any of the sun's planets. Not only does the small size of a planet prevent us from seeing it at such vast distances; more important is the fact that a planet has no light of its own, and so does not shine like a star. When we see the planets belonging to the sun, we do so by the reflected light of the sun. This is very faint in comparison with the light which is directly sent out by a shining body like a star, but as the planets are comparatively near us we are able to see some of them by aid of this reflected light, even with the naked eye.

From this brief survey of the heavenly bodies you will be able to follow the descriptions of a number of separate planets and stars in the following chapters.

Try to keep in mind the important fact that the earth is not the centre of the universe, but is just an ordinary planet which is spinning round once every day and which is also moving round the sun in a curve that is nearly but not quite a circle, completing one revolution in a year.

CHAPTER I

THE EARTH

Dimensions and Shape of the Earth. From the point of view of human beings the earth is the most important of all the planets. Probably if intelligent beings exist on other planets they would not be prepared to share this view, as their own abode would naturally be the most important for them. It is fitting that we should start with a description of the scene of our own life and activities, and a knowledge of the conditions of the earth will assist us in understanding those which exist on other planets.

The earth is not a perfect sphere, though for many practical purposes it can be taken as a sphere. It is slightly flattened at the poles, like an orange, and it bulges at the equator. This peculiar shape is due to its rotation on its axis, about which more will be said later. A line joining the north and south poles, known as the polar axis or polar diameter, is 7,900 miles in length, and a line at the equator drawn perpendicular to the polar axis, known as the equatorial diameter, is 7,927 miles in length.

It is difficult for us to observe the curvature of the earth, because this is so very slight within our usual limited range of vision. One of the simplest proofs of the rotundity of the earth is the gradual disappearance of a ship as it recedes from land, the masts and funnel remaining visible after the hull has vanished. If the sea is perfectly still and the eye is placed close to the surface of the water, it is possible to detect the curvature of the earth over a fairly short distance. The drop below the line of sight is 8 inches for the first mile, 32 inches for 2 miles, 72 inches for 3 miles, and so on. If the drop for 8 miles is required, it is only necessary to multiply 64, which is the square of 8, by 8 inches, and the result, 512 inches, is the required drop.

Another proof that the earth is round is obtained from

eclipses of the moon. An eclipse of the moon is caused by the earth casting its shadow on the moon; the sun, earth and moon being in a line. As the shadow creeps across the face of the moon it is seen to be curved, just as we should expect from a round body like the earth. I have not yet discovered how the flat-earthers explain eclipses of either the sun or of the moon, but as they are highly ingenious in their methods of explanation, I have no doubt that they are able to account for these phenomena, at least to their own satisfaction.

The Earth's Interior and Atmosphere. We have very little direct knowledge about the interior of the earth beyond a few miles in depth, but there is a certain amount of indirect evidence derived especially from a study of earthquakes. This subject is too difficult to explain fully in an elementary treatise, and research on earthquakes, their causes, the speed with which the shocks travel through the earth, etc., is the work of specialists. One thing may be mentioned in connection with the conditions far down in the earth's interior. Earthquake shocks differ according to the nature of the material through which tremors pass. Thus, there is a great difference, which the experts can detect immediately, between tremors sent through a solid mass like a great collection of rocks and those sent through something in a liquid state. By studying these tremors we gather that if we could go down about 2,000 miles into the earth's interior we should come to iron in a molten state, but heavier than the iron which we use every day. From the centre of the earth, therefore, for 2,000 miles all round, there is this dense "central core," as it is called. Above the central core there is the crust which comes to within 40 or 50 miles from the surface, and this consists of rocks which are about four times as heavy as water, for the same bulk. On the top of this crust we have other rocks not quite as heavy as those underneath. (The average density * of the earth is about $5\frac{1}{2}$.) Above this last crust we come to the land, and oceans, and above these the atmosphere.

* By the density of any substance we mean its weight, if the weight of the same bulk of water is taken as the unit.

Like most of the planets, the earth has an atmosphere, hough this differs very much from those which exist on ther planets. It is scarcely necessary to say that life, s we know it, would be impossible without an atmo-phere. Even if life could exist without an atmosphere could last only a very short time, because the bombard-ment of the earth's surface by meteors would soon estroy it. These meteors, about which something will e said in Chapter V, are usually burnt up, owing to the eat produced by their friction with the atmosphere, at eights of 30 to 40 miles. They are moving with high peeds—varying from 10 to 45 miles a second—and ecome intensely hot by their collision with the molecules f the atmosphere. Because they become white-hot for few seconds as they rush along, their sudden bright ppearance has been responsible for the usual title, shooting stars." Sometimes the larger meteors are ot completely burnt up in the atmosphere and hence each the earth; they are then known as " meteorites," nd the study of these bodies has become a very mportant branch of science in recent years. As meteors re sometimes visible at heights of over 100 miles, we now that the atmosphere must extend to this distance, hough it is very thin at such heights. Aurorae, known n the northern hemisphere as the " Northern Lights," ave been observed at much greater heights still, from vhich it may be presumed that even there an atmosphere f some kind exists.

The atmosphere is important from more points of view han assisting with sustaining life. In comparatively ecent times we have discovered that certain parts of it re responsible for reflecting radio waves. The " Kennelly-Heaviside layer," discovered in 1902 by Kennelly in he United States and Heaviside in England, is generally ound at a height of about 65 miles, but its height may ary by as much as 20 miles on either side of this. This ayer reflects radio waves, just as an ordinary mirror eflects light, and turns them back to the earth. Higher till is another layer, named the Appleton layer after its iscoverer. Its height may be as much as 250 miles or s low as 90 miles, and it too reflects radio waves back to

earth. There is a lower layer which is only about 30 miles above the surface of the earth, and this serves the useful purpose of reflecting the long waves back to earth, but it is not very effective in reflecting the short waves. The other layers referred to are able to do this much better.

Revolution and Rotation of the Earth. The earth revolves round the sun, completing its journey in a year and moving with a speed of about $18\frac{1}{2}$ miles a second. The path which it traces in its yearly motion is not a circle but an ellipse, and the same kind of curve is pursued by all the planets and comets in their revolution round the sun. There was a time when people thought that circular motion was " perfect," and this view was responsible for delaying important discoveries in connection with the movements of the planets. The Greek astronomers tried to represent the movements of the heavenly bodies by circles, and in the Middle Ages astronomers of note, like Copernicus and Tycho, retained circular motion in their explanations. Kepler tried to represent the motions of the planets on the same pattern, but finally gave up the attempt, and to his great delight discovered that the simplest of all oval curves—the ellipse—satisfied the observations of the positions of the planets. He announced his law about motion in an ellipse in 1609, and his book *The Harmony of the World*, which contains this and his other laws, was published nine years later.

An ellipse is easily traced on a sheet of paper with the aid of two pins and a piece of thread in the form of a loop. Insert the pins in the paper; place the thread over them and pull it tight with a pencil point, which can now be moved along the paper, tracing out an ellipse. When the pins are moved farther apart it will be noticed that the ellipse becomes flatter. If the pins are brought closer together the ellipse becomes more like a circle, and when the two pins merge into one on the same spot, the curve becomes a circle. The point marked by each pin is called the focus of the ellipse. A very elongated ellipse is shown in Fig. 9, Chapter V.

The sun is in one of the foci of the ellipse which the

arth—in common with all the other planets—describes
n its orbital motion round the sun. For this reason no
lanet keeps a constant distance from the sun in its
rbit, the name given to the course of a planet or any
ther body round the sun. No two planetary orbits are
ne same in shape, though all are ellipses. Some are
nore oval than others, and hence show a greater differ-
nce between the nearest and the farthest distances from
ne sun than when the shape of the ellipse is more like
circle. The small scale on which the diagrams are
rawn shows the planetary orbits as circles.

In addition to the earth's revolution round the sun
nere is also its daily rotation, which gives us the
uccession of day and night. The difference between
evolution and *rotation* should be carefully noticed,
ecause astronomers use the words to denote two
istinct movements. *Revolution* is motion around an
utside centre, as when the earth or any other body
noves round the sun, which is then the outside centre.
Rotation is motion around an axis within the body
self. A good illustration can be arranged by means of
n orange through the flattened ends of which a needle
inserted. If the orange is carried round a central body,
ay a lamp on a table, this movement is similar to the
arth's orbital revolution round the sun. If it is spun
ke a top by turning the needle, this movement is
imilar to the earth's axial rotation. Of course there is
o real axis through the earth corresponding to the
eedle in the orange; the earth's axis is the *imaginary*
ne which is drawn from pole to pole. As explained in
ne Introduction, the axial rotation of the earth from
vest to east is responsible for the apparent movement
f the heavenly bodies in the opposite direction.

A very important effect of the axial rotation is that it
eeps the earth's axis pointing in the same direction—
lmost exactly, in fact, towards the pole star, which is
uch a useful guide to sailors and explorers. If the earth
id not spin like a top, its axis would not tend to maintain
his steady position. In the well-known toy called a
yroscope—a special kind of top—we see the same
orces at work. When we hold a spinning gyroscope in

our hand we find it difficult to change the direction of the axle; the gyroscope seems to behave like a live thing, stubbornly resisting every effort to tilt the axle. At the same time we can easily carry the gyroscope round the room, so long as we do not try to make the axle point in a new direction. The reasons for this curious behaviour of a spinning mass cannot be given without a great deal of complicated mathematics, but any one can convince himself of the facts by playing with the toy. If the earth, which rotates once in 24 hours, does not seem to be spinning fast enough to behave like a gyroscope, we must remember that for its size it is really rotating very rapidly. A man standing at the equator is carried round at a speed of 1,000 miles an hour.

It should be added that the earth's axis does not keep *absolutely* in the same direction all the time. Like a top near the end of its spin, it " wobbles," and the axis has also a revolution of its own, but as the latter is slow and the former is very slight, we can leave them out of account when explaining how the behaviour of the earth accounts for the four seasons.

Explanation of the Seasons. It has already been explained that the earth revolves round the sun in an orbit which is an ellipse. If we imagine a line drawn from the centre of the sun to the centre of the earth, as the earth moves round the sun this line would sweep out a flat surface which astronomers call " the plane of the ecliptic." We have not yet said anything about the position of the earth's axis with reference to this plane. If the axis had been perpendicular to the plane of the ecliptic there would have been no seasons, as any particular place on the surface of the earth would get the same amount of heat and light each day all the year, except, of course, for cloud interference. There would be no change from long cold winter nights to long warm summer days. The earth's axis, however, is tilted at an angle of about $66\frac{1}{2}°$ to the plane of the ecliptic. Fig. 2 shows how this tilt gives us the seasons; the broken line represents the orbit of the earth. Readers will find the explanation easier to follow if they use a ball about 6 inches or more in diameter on which two marks are

aced which correspond to P and Q, the north and outh poles respectively.

Starting with the earth in the position 1, let the surface f the paper represent the plane of the ecliptic in which he sun S is situated. In position 1 let the axis PQ be clined to the plane of the paper at an angle of $66\frac{1}{2}°$. will be found, by using the model, that there will be undreds of positions for the axis with this inclination. hus P may be nearer to S than Q is, or Q may be

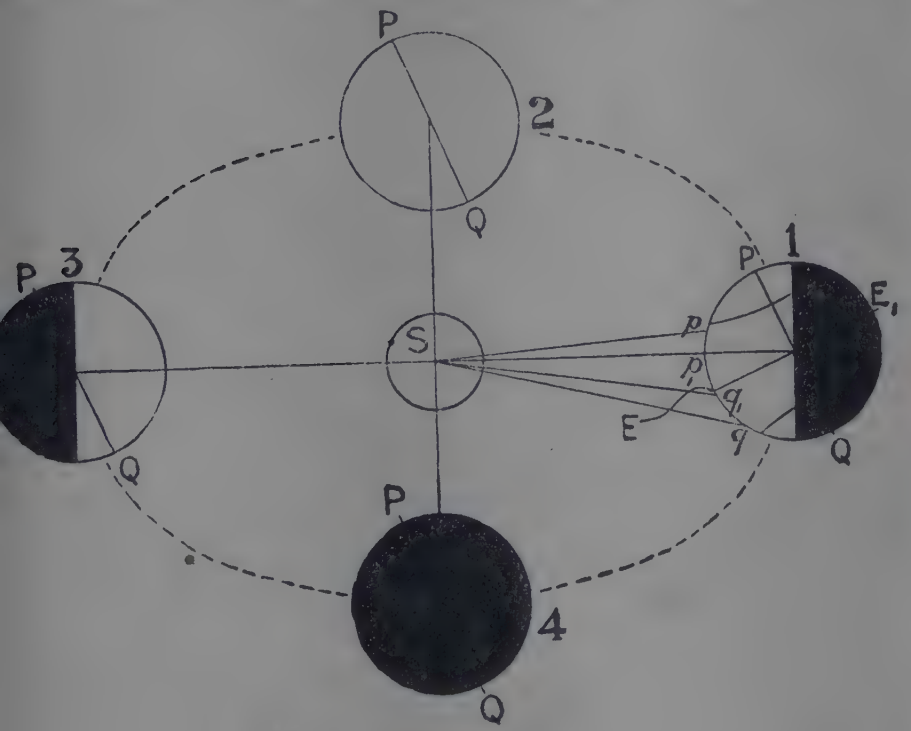


FIG. 2.

earer to S than P is, and there are numerous intermediate ositions, although the inclination of PQ to the plane of he paper remains at $66\frac{1}{2}°$. If, however, it is decided hat P shall be as near to S as is possible, and therefore Q as far away from S as is possible, *there is only one osition in which the axis PQ can be placed*; in this osition the north pole, P, is tilted towards the sun, the outh pole, Q, being tilted away from the sun, as far as ossible in each case: 1 is the position which corresponds o midsummer on the northern hemisphere and to mid-inter on the southern hemisphere.

To show why a place in the northern hemisphere receives more heat at this time than a place at the same latitude in the southern hemisphere, draw a line from S to the centre of the earth, cutting the surface of the earth at p_1. EE_1 represents the equator and q is a point on the surface of the earth as far south of E as p_1 is north of E. From S draw a line Sp making a small angle—say 5°—with Sp_1, and another line Sq_1 making the same angle with Sq. It is clear that the same quantity of heat and light will come from the sun between the lines Sp and Sp_1 as is received between the lines Sq and Sq_1, and hence pp_1 will get as much light and heat as qq_1. Now it is easily seen from the diagram that qq_1 is greater than pp_1, and hence, as it receives the same amount of light and heat, any particular part of it receives less than an equal part in pp_1. The situation is similar to that of a beleaguered garrison with only a certain store of provisions. If the numbers in the garrison are increased by any means, the same quantity of food, rationed to last the original garrison for, say, three months, must now be divided among greater numbers; hence each man will receive less.

The following simple experiment will make this quite clear: Flash a circular beam of light from an ordinary torch on to a piece of cardboard about a foot distant from the torch and held in such a way that its plane is nearly perpendicular to the light beam. Notice how much of the cardboard is covered by the beam, and then tilt the cardboard so that it is inclined at a considerable angle to its first position. It will now be seen that the light from the torch covers a much larger surface of the cardboard than it did in the first position, so that any definite area, say a square inch of the cardboard, will receive less light than it did in the first instance. The same remark also applies to the heat given out by the torch, but as this is very small it would be impossible to measure it by ordinary methods. The principle is the same, however, for both heat and light, and it will now be clear why position 1 in the diagram corresponds to midsummer in the northern hemisphere and to midwinter in the southern hemisphere.

We follow the same principle in many familiar actions.

When we are reading we hold the page so that the light falls full upon it, and not at a low slant, as we find that we get more illumination in that position. When we are airing a garment in front of a fire we place the article so that the heat-rays fall vertically upon it.

It has already been pointed out that the axis *PQ* maintains a constant direction in space as the earth moves round the sun. In position 3, therefore, the axis points in the same direction as it did when the earth was at 1. This can be illustrated on the model by making *PQ* point to a top corner of the room as the model is carried round the central body which represents the sun. The circle in which it is moved should not be large, as otherwise pointing *PQ* to the corner of the room will not necessarily ensure that *PQ* remains nearly parallel to itself; in other words, pointing nearly in the same direction. In position 3 we have the exact opposite to that which we found at 1. The south pole, *Q*, is now tilted towards the sun, and the light and heat will fall more directly on the southern than they do on the northern hemisphere; *Z* corresponds to midsummer on the southern and to midwinter on the northern hemisphere. In the positions 2 and 4 the axis is not pointed either towards or away from the sun, and places at the same latitude in each hemisphere will then receive the rays from the sun at exactly the same angle. These positions correspond to the autumn and spring equinoxes respectively, when day and night are equal in length.

There is another factor which assists in causing the seasons. When the sun's rays fall obliquely on either hemisphere during its winter, they must pass through a greater thickness of air than they do when they strike the earth directly. The air, even when it is free from cloud, absorbs a certain amount of the sun's heat, and hence has some cooling effect of its own, quite apart from the lessened heat due to the rays falling obliquely. While this effect is not very large, it plays its part in producing the seasons.

Strange as it may seem at first sight, the distance of the earth from the sun has very little to do with the difference between summer and winter. In fact, in the northern

hemisphere the earth is about three million miles *nearer* to the sun at midwinter than it is at midsummer. In the southern hemisphere, on the other hand, it is about three million miles nearer to the sun at midsummer than it is at midwinter. One might think that the summer at a certain place on the southern hemisphere should be hotter than a place in the same latitude on the northern hemisphere, but there are many other factors, such as height above sea-level, distribution of land and water, direction of prevailing winds, etc., which are also important in determining the temperature of a locality.

It will be seen from Fig. 2 that in position 1 the sun does not set in regions near *P*, the north pole, or rise in places near the south pole. The axial rotation on *PQ* does not take any locality between *P* and the portion shaded dark away from the light of the sun. Between 1 and 2 the continuously illuminated patch will slowly decrease, and at 2—the autumn equinox—the continuously illuminated part will not extend south of *P*. Between 2 and 3 *P* is tilted away from the sun and the axial rotation will not take *P* into the sunshine. At 3 there is perpetual darkness over a large portion of the regions surrounding *P*. When we speak of perpetual darkness we are leaving out of account the effects of twilight, which shortens the polar night very considerably.

Questions

1. If anyone told you that the earth is not round, what proofs would you give to show that it is round?
2. Give a brief account of what is believed to be the condition in the interior of the earth.
3. Describe the difference between the two motions, revolution and rotation. Which of them causes the succession of day and night?
4. How would you propose to arrange the inclination of the axis of the earth, or any planet, with regard to the plane of the ecliptic, to produce the following effects : (*a*) no changes in the seasons ; (*b*) the greatest possible changes in the seasons?
5. How much nearer are we to the sun at midwinter in the northern hemisphere than at midsummer? Is our winter much milder on this account than the winter of the southern hemisphere?
6. Explain why there are 6 months of darkness and 6 months of day at each pole in turn. Why do places at some distance from each pole get less than 6 months' continuous darkness and light?
7. Show from Fig. 2 how far north you would go to see the midnight sun at midsummer.

CHAPTER II

THE MOON

The Motion of the Moon. The moon is our nearest eighbour and, next to the sun, is the most useful for our eeds. It is true that we do not depend on the moon r our very existence, as we do on the sun, but if the oon disappeared from the heavens we should miss her ry much, for two reasons. First of all we should miss e moonlight, which, though not indispensable, yet nders great assistance to the denizens of this planet, pecially in the winter months. Then we should miss r influence on the seas, because she is more important an the sun in producing the tides.

The moon depends on the earth for her motion in the avens. We have only to notice how she moves farther st among the stars from the first appearance of the escent until full moon to infer that she is revolving ound the earth just as the earth is revolving around e sun. Perhaps this statement should be modified ghtly to prevent misunderstandings. When one avenly body revolves around another we are accustomed think of the larger body remaining at rest. Actually th bodies revolve around their common centre of avity. This principle can be illustrated very simply attaching two weights to the end of a rigid rod, ding the position of the rod where it balances on a vot (known as the centre of gravity of the system), and rning the rod on its pivot. This gives a rough picture the revolution of the heavenly bodies, and if one body much heavier than the other, the centre of gravity may inside the heavier of the two. This happens in the se of the sun and the earth. The sun weighs more an 300,000 times as much as the earth, so that, in ite of the enormous distance between them, the centre gravity of the sun–earth system is only about 300 les from the centre of the sun—a very small distance r a body the diameter of which is 864,000 miles.

The moon's weight is less than one-eightieth of the earth's weight, and as her distance is about 240,000 miles, the centre of gravity of the earth–moon system, known as the " barycentre," is 3,000 miles from the centre of the earth. This result is obtained by dividing 240,000 by 80. As the earth's radius is 4,000 miles, the centre of gravity of the earth–moon system is about 1,000 miles below the earth's surface. It is interesting to know, therefore, that our planet, in addition to its revolution round the sun, is also revolving round a point 1,000 miles below its surface. The moon revolves round the earth, or rather round the barycentre, once in 27 days 7 hours, and hence the earth's centre also revolves round this barycentre in the same period. As the moon always turns the same face towards the earth, we never see her other side, but it probably resembles the face that we see.*

Phases of the Moon. The revolution of the moon round the earth is responsible for the " phases " through which she passes in a lunar month and with which everyone is familiar. The light which the moon sends to us is not her own, because, unlike the sun and stars, she has no light or heat. When we see her we do so because she reflects the light which the sun sends to her. If there were inhabitants on the moon they would see the earth in just the same way as we see our satellite—by the light of the sun reflected by the earth. Fig. 3 shows the reasons for the moon's phases, but readers are strongly advised to make a small model which will tell them more about the lunar phases than many pages of explanation. In the diagram *E* is the earth, *S* the sun, and *M* the moon in various positions in her orbital motion around the earth. In position 1 the sun, moon, and earth are nearly in a straight line, and the portion of the moon turned towards the earth is in the dark, so that she is invisible. It has already been pointed out that the light which we derive from the moon is merely reflected sunlight; at 1 this sunlight is reflected away from the

* This is not quite correct, as the moon has a slight libration—a rocking from side to side—in consequence of which we see 59 per cent of her whole surface.

arth. In position 3 the hemisphere of the moon which is luminated by the sun is turned towards the earth, and ne moon looks like a circular disc. In this case we speak f the moon being full. In intermediate positions, say t 2 or 4, the dark side is not turned towards us completely nor is the illuminated side fully turned towards us. From the diagram we see that half the illuminated hemisphere is visible to us; in this position we speak of the half moon." Between 1 and 2 less than half the

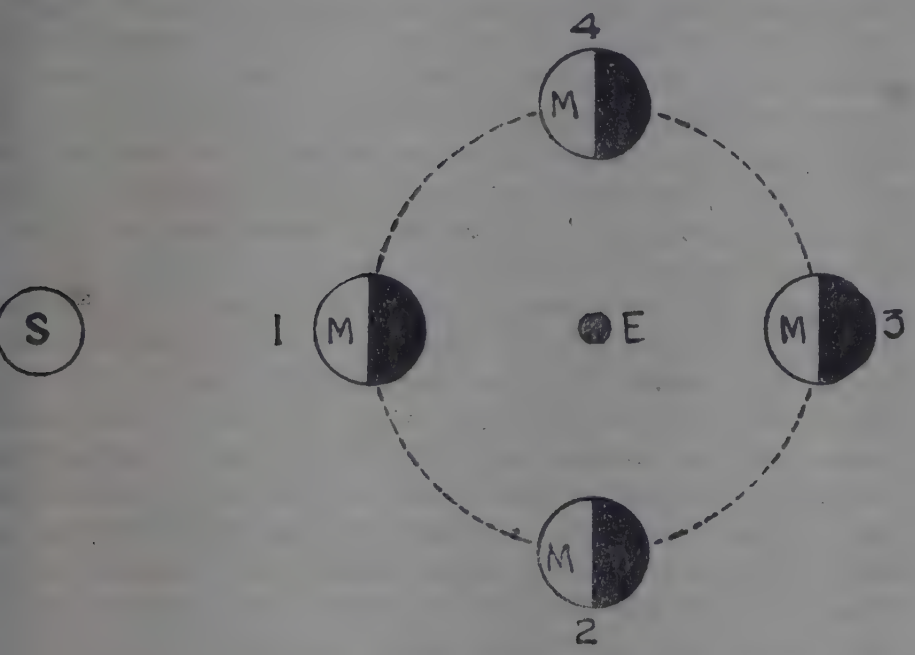


FIG. 3.

emisphere will be visible, and very close to 1 a thin rescent will be seen which we describe as the "new oon." In positions after full moon the phases will epeat themselves, but the portions which we see as ree-quarters moon, half moon, etc., will now appear the reverse order, and the crescent part will be on a ifferent edge of the moon.

The model can consist of two spheres—two billiard or nnis balls—to illustrate the phases, and the light can e supplied by an electric torch which represents the sun. he plane of the torch and the ball which is supposed to e the earth should not pass through the other ball

which represents the moon. In fact, if the torch and the earth ball are on a table, the other ball should be a little above the level of the table. On moving the moon ball around the other one it will be seen how the illumination of a hemisphere appears to observers on the earth, according to the relative positions of sun, earth, and moon. The reason for placing the moon ball above the table, and not in the plane of the earth and sun, is that the moon does not revolve round the earth in the plane of the ecliptic; her orbit is inclined to this plane at an angle of over 5°, and hence the moon is sometimes north and sometimes south of the ecliptic.

The Moon's Orbit is an Ellipse. Just as the earth's orbit round the sun is an ellipse, so that of the moon round the earth is also an ellipse. For this reason her distance from us is not always the same. Her greatest distance is 252,710 miles and her least distance 225,463 miles. It is impossible in an elementary work to give a full description of the method used for finding the moon's distance from the earth, but a brief outline will be of interest. Readers know that a surveyor can find the distance of an object without direct measurement. All he does is to measure a base line a few hundred feet in length, set up a theodolite * at each end of this line, and measure the angles between the base line and the object in each case. Knowing two angles of a triangle and the length of a side, it is possible to find the lengths of the other sides. Very great accuracy can be obtained by this method; in fact it was used in preparing our Ordnance Maps.

The same principle is applied in measuring the distance of the moon from the earth. In this case, however, a base line of a few hundred feet would be of little use, as the moon is so far away. Astronomers used one a few thousand miles long connecting two observatories, one in each hemisphere, thus securing the longest base line which could be conveniently used. By measuring the distance of the moon at different times they found that her orbit is not circular, but an ellipse.

Size of the Moon. Knowing the moon's distance, it

* A theodolite is an instrument for measuring horizontal and vertical angles.

s easy to find her diameter. It is only necessary to neasure the angle which her diameter "subtends" at ne earth—that is, to find the angle between a line from ne eye to the extreme left-hand edge of the full moon nd a line from the eye to the extreme right-hand edge. A simple calculation then gives the moon's diameter, vhich is 2,160 miles. The angle which the moon ubtends at the earth varies a little, owing to the moon's ifferent distances from the earth.

There is a certain ambiguity in describing the distance f the moon from the earth. It does not mean the istance from the surface of the moon to the place where ne observer on the earth is standing, but the distance etween the centres of the earth and the moon.

Force of Gravity on the Moon's Surface. On the arth we know that a body falls 16 feet in one second, 4 feet in two seconds, and so on, but on the moon a body vould fall only $2\frac{1}{2}$ feet in a second, 10 feet in two seconds, nd so on. If you could throw a stone 60 feet high on ne earth you could throw it over 360 feet high on the noon. Similarly, a man on the moon would have little ifficulty in clearing a wall 25 feet high, or even higher. he reason is that the moon's attraction for bodies is nly about one-sixth that of the earth's attraction, and nis is due to the moon's weight being so much less than nat of the earth. There are many small bodies like the ninor planets, about which we shall say something later, ne attractions of which are so small that if a man mped upwards from one of them he would never eturn. The body would lose control of him, and he vould just go out into space, perhaps to be captured in ne course of myriads of years by another larger body.

The Moon Has no Atmosphere. The moon to-day as no atmosphere. If she ever possessed an atmosphere has disappeared, and this is not surprising when the nall force of gravity on the surface of the moon is onsidered. The molecules of our atmosphere are in onstant motion, and if any of them in the upper regions f the atmosphere, where they would not be so likely to ollide with other molecules, had ever a speed of 7 miles second or more—which is the *velocity of escape* for the

earth—they would move off into space, the earth losing control of them. If a big gun could project from the earth a shell with a velocity of 7 miles a second, the shell would not return. On the moon the corresponding figure is about 1½ miles a second, and if she ever had an atmosphere it is obvious that it would be lost much more easily than is the case with the earth.

Although Prof. W. H. Pickering thought he had detected signs of vegetation on certain parts of the moon, which would imply the presence of an atmosphere, English astronomers were unwilling to accept his results, and it is now generally agreed that the moon is utterly devoid of an atmosphere. Observations support this view. When the moon comes between us and a star, the star is hidden from us for a time and is said to be occulted. In every case of occultation by the moon the star vanishes suddenly and completely. If the moon had an atmosphere, some of the star's light, even when the star had just gone behind the moon, would be scattered by the atmosphere, and for this reason the star would "fade out" instead of disappearing in an instant.

The moon is, therefore, a dead world from which all life, if it ever existed there, departed many millions of years ago. It may be added that there is no trace of water or vapour on the moon. Without an atmosphere to screen the heat of the sun, the side of the moon facing the sun gets very hot—hotter, it has been estimated, than boiling water. On the other hand, the sunless side is very cold—considerably more than a hundred degrees below the freezing point of water.

Physical Appearance of the Moon. A small telescope or a pair of field-glasses will reveal the wonderful beauty of the moon's surface, with its rugged mountain ranges, its plains, and, most wondrous sight of all, its thousands of craters. These "craters" have very little in common with the volcanic craters on the earth, which are few and also small in comparison with those on the moon. More than 30,000 lunar craters have been mapped up to the present. Their diameters vary from about 150 miles down to less than one-fourth of a mile, and there must be many others so small as to be invisible even in our

argest telescopes. The title "craters" may be unfor-unate, as it conveys the idea of openings on the top of mountain cones from which molten material is occasion-ally ejected. The larger craters are great walled plains, heir rims rising as high as 10,000 to 20,000 feet above he general surface of the moon, while their interior is far below the moon's surface—sometimes as much as hree miles.

There has been much speculation about the origin of he lunar craters, but it is impossible to say definitely now they were formed. Sir George Darwin suggested a theory many years ago about the origin of the moon and also about how the craters were formed. He believed that some thousands of millions of years ago, when the earth rotated more rapidly than it does now, he moon was thrown off, and has been receding ever since. If this did occur it seems that the moon would be of similar material to the outer portions of the earth, and actually the density of the moon is nearly the same as that of the earth's outer crust (see p. 8). At the ime when the moon separated from the earth it is believed hat the earth was in a molten condition, and of course he moon was likewise, but as it was so much smaller han the earth, it cooled more rapidly. As we should expect this cooling to occur first near the surface, where n time a solid crust would be formed (the interior remain-ng molten for a longer period), it has been thought that something like enormous bubbles were formed on the cooling exterior. When these burst, craters like those which we now see on the moon would be formed.

This theory is open to a number of objections. Darwin himself admitted that it was "only a wild speculation, ncapable of verification," and indeed in recent times it has been shown to be extremely doubtful whether the moon broke off from the earth, as Darwin suggested.

Another explanation of the lunar craters is that there was once volcanic activity on the moon, but on a scale so enormous that the small volcanic activity on the earth can give no conception of it. Many objections can be made against this solution of the puzzle, but it will be sufficient to point out that if things happened so, there

should be some trace of the enormous amount of material thrown out by the volcanoes; in most cases such material is lacking.

Another theory, probably more feasible than the other two, is that the lunar craters were formed by bombardment by meteorites which varied in size from small bodies up to objects many miles in diameter. A large object crashing on the moon at a speed of 30 miles a second or more would have an effect like a bomb and would produce a large crater. Even if the body struck the moon on the slant, the crater produced, assuming the effect is of an explosive nature, would still be circular, as most of the lunar craters are. We have a crater formed in this way on the earth—the Arizona crater—which is about 4,000 feet in diameter and 600 feet deep, and it is certain that the meteorite which was responsible for it fell obliquely, at an angle of about 45°. The theory of the formation of the lunar craters by meteorites would be strengthened if there were many more of these large depressions on the earth, formed by the impact of meteorites. On the other hand, it is possible that if a large number of such craters had been caused in this way, all traces of them might have been destroyed by the action of air and water in the course of hundreds of millions of years. No such action could take place on the moon, where, as we have seen, there is no atmosphere or water; hence if craters had been formed on her surface by bombardment they would remain intact. On the whole, the theory of meteoric action is the most plausible explanation of the craters on the moon.

The Moon and the Tides. The most important effect which the moon has on the earth is in the production of the tides. The pull of the moon on the ocean waters tends to draw them slightly towards her. Indeed, the surface of the earth is pulled as well, but as it is too rigid to give way very much, the chief visible effect is on the water. If the moon merely heaped up the waters on the side of the earth next to her, we would have a single high tide sweeping over the seas once in every 24 hours. The action of the moon, however, heaps the waters up on the far side of the earth as well as on the near side,

us giving two high tides every 24 hours. Why it ould do so is rather difficult to explain without going to abstruse mathematics,* but there is no doubt about e fact, which anyone living at the seaside or on a tidal ver can verify for himself (see Fig. 4).

The sun plays a part as well as the moon in tide-aking. In spite of his enormous mass compared with at of the moon, his effect on the tides is less than that the moon. This is because he is so far away from the rth—nearly 400 times as far as the moon. When the n and the moon pull together we get the big rise of the

g. 4.—The moon draws the waters of the ocean towards her and hence produces the tides. On the other side of the earth there is also a high tide at the same time.

spring tides," and when they pull against each other get "neap tides," in which the difference between gh and low water is less. During spring tides the sun, oon, and earth are in a line, or nearly in a line, with one other, and the tides made by the sun are added on to ose made by the moon at the same place. At other nes, when the moon is out of line with the earth and n, the moon and sun each makes a tide of its own at fferent parts of the earth, but the tide produced by the oon is the greater of the two. That which the sun uses diminishes the moon tide, and so we have low es at a place—the neap tides. These changes in sition of the sun and moon account for the variations the tides, which can be predicted and are listed in

* I gave a fairly elementary mathematical proof of the subject in e *Journal of the British Astronomical Association*, 35, 2, November, 24, and also 52, 8, September, 1942, but the dynamics of these bers are beyond the scope of this work.

Tide Tables prepared for the use of mariners and harbour authorities.

The Moon and the Weather. It is remarkable that many people still believe that there is some connection between the moon and the weather. Weather records, however, show that this view is utterly devoid of foundation. Most people who hold the belief fail to carry out any regular observations, and they are impressed with the cases where good weather follows a change in the moon, but ignore those cases where no such connection is found. Sometimes it is said that if the new moon comes in with fine weather we may expect a spell of "set fair." It is forgotten by many that we can generally see the new moon only if the weather at the time is fine, and the meteorological conditions may then be favourable for a period of good weather. The meteorological conditions, however, were not determined by the moon, but merely happened to coincide with her phase. If there is a spell of wet weather at the time of new moon, we shall not be able to see her, and this spell may continue for several days. But the continuation of the wet weather has no connection with the change in the moon.

Questions

1. What are the chief uses of the moon to the inhabitants of the earth?
2. Give reasons for believing that the moon moves round the earth.
3. Suppose that you were asked by someone utterly ignorant of astronomy to explain the phases of the moon, how would you proceed? Could you explain from a model why the horns of the moon always point *away from* the sun?
4. Why do you think that the moon has no atmosphere?
5. State briefly the theories to explain the origin of the lunar craters.
6. Does the moon affect the weather?

CHAPTER III

THE SUN

Size and Temperature of the Sun. Among the myriads f bodies which are scattered about in the universe the un is by far the most important of all for us. Without ie heat of the sun no life could exist on the earth, which vould then be intensely cold, even the oceans becoming a reat mass of ice. Yet the sun is merely one of millions of illions of stars and only an ordinary star, not merely in ze, but also in mass and temperature. Some people nd it difficult to think of the sun as a star because its ze and brightness are in such contrast to the smallness nd feeble light of the stars. The contrast, however, is ue to the fact that the sun is so close to us compared ith the distance of even the nearest star. The average istance of the sun from the earth is only 93 million iles—we say " only " because the nearest star is about 70,000 times as far away—and so, as against the istance of a star, the sun is very close to us. We know a t about the sun, not only about his composition, his mperature, his surface features, and so on, but also out his size, density, weight, etc. It is not possible describe how all the facts are found out, but it will be fficient to give a summary of the chief things which we ow with absolute certainty.

The sun's distance from the earth varies from ,556,000 miles to 91,444,000 miles, and it attains these stances early in July and January respectively. His ameter is 864,000 miles and his density 1·41. In spite this low density, his mass is enormous and is presented in tons by the figure 2 followed by 27 phers, which is 330,000 times the mass of the earth. ie temperature of the sun at his surface is 6,000 grees on the centigrade scale—written 6,000° C.—but, gh as this appears, it is very low compared with the mperature near the sun's centre. It has been estimated

that this must be about 20 million degrees Centigrade or even higher. It is difficult for our minds to grasp fully the meaning of these figures, but the following simple illustration will assist us in understanding the meaning of such a temperature. Suppose we had an ordinary-sized stove which could withstand any temperature, however high, and we raised it to 20 million degrees Centigrade. Within a radius of hundreds of miles everything would be burnt up by the intense heat.

Origin of the Sun's Heat. If the sun is continually sending out heat from his surface, which has a temperature of 6,000° C., it might seem merely a matter of time before he burns himself up completely. It is not really correct to say that the sun is " burning," and the energy which supplies the heat does not arise, as it does in a fire, from ordinary chemical action. Radium and other radio-active bodies are known to give out an enormous amount of energy when their atoms break up, and other elements are capable of doing the same under certain conditions. This *subatomic energy* accounts for the heat radiated by the sun and by the other stars as well, so we need not fear that the sun will soon burn himself out and leave our planet and the others to perish from the intense cold. We need not fear, on the other hand, that the sun will suddenly blaze forth on account of all this enormous amount of subatomic energy and burn up the earth.

Rotation of the Sun. The sun rotates on his axis just as the earth does, from west to east, but takes longer to complete a rotation. In the neighbourhood of the sun's equator it requires about 25 days to move round once, but the strange thing is that it takes a *longer time* in places north and south of the equator, and at the poles the rotation is so slow that 34 days are necessary. This fact suggests that the sun cannot rotate as a whole like the earth; different portions of his surface are moving round at different speeds. This is the sort of thing that could happen with a body made of gases, and the sun, like all the stars, is gaseous, the high temperature preventing anything from becoming solid either in the interior or at the surface.

The Sun's Surface. The study of sunspots is a

vourite hobby with some amateur astronomers, and a rge telescope is not necessary to carry out the observaons. If you ever use a telescope, however small it may e, to look at the sun, make sure that you have a piece of noked glass between your eye and the eyepiece of the lescope. If you do not take this precaution you may ceive very serious injury to your eye. (It is possible see large spots on the sun by using a piece of smoked ass without a telescope, as the glass shuts out some of e glare of the sun.) These spots are very useful for etermining the times of rotation of the different parts of e sun. It has been found that sunspots run in cycles ver a period of 11 years. When the sunspots are at eir lowest it is possible that for months the sun's sc shows only a few or perhaps no spots. Then they pear in increasing numbers, until the greatest number reached in about $4\frac{1}{2}$ years. The numbers decrease ter this for about $6\frac{1}{2}$ years, when the spots are few or tirely absent. After this they start to increase again, d pass through the same changes in the same period. here is still much doubt about the causes of these anges.

Sunspots are much cooler than the rest of the sun's rface, and they look dark only by contrast with the ighter regions which surround them. They are caused whirling columns of gases which rise from beneath e sun's surface and lose heat by their expansion. At e same time warmer gases from the sun's surface are awn into the whirlpools produced by the rising gases, d a sort of circular motion takes place. When the nspots are very active the magnetic compass is affected d there are displays of the aurora or "northern hts," while radio service is often upset. There is no ysterious connection between the sunspots and magnetic storms" as they are often called. They are e to the arrival of showers of electrons or small gative charges of electricity from the disturbed part the sun. When these electrons reach our atmosphere out two days after leaving the sun they produce tain electrical conditions which disturb our electrical d magnetic instruments. Sometimes the disturbances

upset our telegraphic and telephonic services, but the are never dangerous to life.

Eclipses. The model described in the previous chapte will help to explain how and when eclipses of the sun an moon occur. With the moon revolving round the earth and the earth and moon round the sun, there are certai positions in which the earth's shadow falls on the moo (giving an eclipse of the moon), and other positions i which the moon comes directly between the earth and th sun (giving an eclipse of the sun). If the moon move all the time in the plane of the ecliptic there would be a eclipse of the moon every full moon and an eclipse c the sun every new moon. We know, however, that th path of the moon is inclined to the plane of the eclipti Owing to this tilt in the moon's orbit, the three bodies— the sun, moon, and earth—do not come into lin regularly at new moon and full moon, but at less regula intervals. Astronomers are able to calculate the time when these events occur, and so are able to predict th occurrences of eclipses hundreds of years before the take place.

Here are two rules worth remembering in connectio with eclipses:—

(1) In one year there cannot be more than seve eclipses: five of the sun and two of the moon, c four of the sun and three of the moon.

(2) In any year there cannot be less than tw eclipses of the sun.

Eclipses are not always total—that is, only part of th sun may be hidden by the moon in a solar eclipse, an only part of the moon may be covered by the earth shadow in a lunar eclipse. We then speak of th eclipses as "partial." A total eclipse of the sun is a gre event for astronomers. It is a fortunate circumstanc that the moon is of such a size and at such a distanc from the earth that it appears to be practically of the sam size in the heavens as the sun. At times it just covers th sun's disc, and astronomers are able to obtain a bett view of certain portions of the sun's atmosphere tha extend far beyond the disc, and in particular of th

orona—a pearly white envelope of wonderful beauty hich can be seen best during a total eclipse. By notography and other means much valuable information obtained about the atmosphere of the sun which cannot e obtained at other times.

During solar eclipses other than total the moon is a ttle farther away from the earth, and some portion f the sun's disc is visible round the moon. Such an lipse is called a partial eclipse. It has not the same lue to the astronomer as a total eclipse.

As a total eclipse of the sun is such an important event, tronomers make expeditions to different parts of the rth where it can be seen. A total eclipse of the sun is ot visible everywhere, but over only a very limited ortion of the earth's surface. The width of the shadow rown by the moon on the earth is only about 50 miles, nd anyone inside this strip, which sweeps over a great art of the earth's surface, can see the eclipse as total. hose who are just outside the strip can see it only as a artial eclipse, and hence it is important for astronomers ho want to see a total eclipse to know exactly where this rip runs. Not every astronomer is able to do the lculation necessary to determine the precise track and ve the instant when the eclipse begins or ends. This is ry specialized work for the mathematician, and so eat is the accuracy of his computations that he can edict to within a second or two the time of beginning d ending of an eclipse at any place. Mistakes would very disturbing to those who go to the other end of e earth with elaborate appliances to see and photograph otal eclipse of the sun (a lunar eclipse has not the same lue as a solar eclipse), and woe to the mathematician ho made even the slightest error! Such a thing, owever, never occurs, and when an eclipse is predicted r a certain time and place you can be absolutely re that it will take place then and there.* The one ing which the mathematician or anyone else cannot edict months ahead is the condition of the weather. nfortunately even a passing cloud will prevent astrono-

* The next total eclipse of the sun visible in the British Isles tually only in Cornwall) will be on August 11, 1999.

mers from seeing an eclipse and will spoil all the months of preparation, but this will not deter them fro going off on future expeditions when other eclipses a due. (See Figs. 5 and 6.)

Gravity of the Sun. In the chapter on the moon w

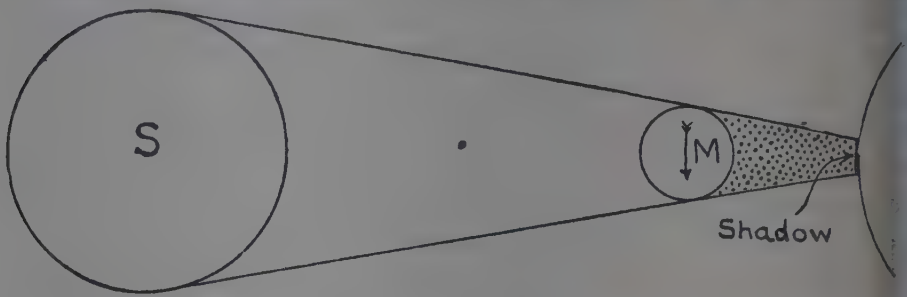


FIG. 5.—Showing a total eclipse of the sun. The moon casts shadow on the surface of the earth, and this shadow swee rapidly over the earth as the moon revolves in the directio shown by the arrow.

spoke about the force of gravity there—about one-sixt of what it is on the earth. If you were on the sun yo would find conditions just the opposite. The force gravity on the sun is 28 times as much as it is on the earth so if your muscles were just as strong there as they a

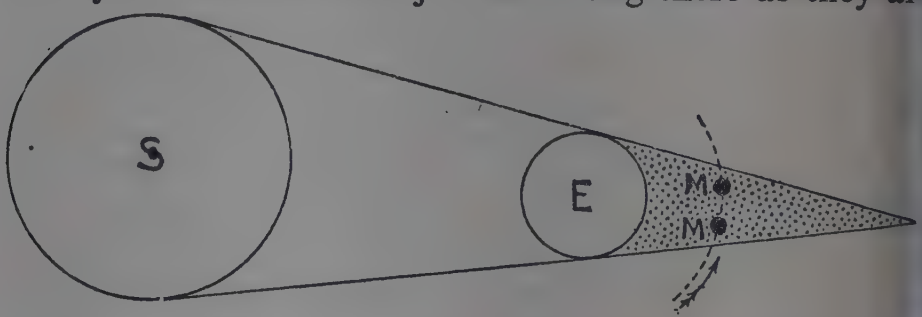


FIG. 6.—An eclipse of the moon. The earth casts a shadow an the moon is shown in two positions inside this shadow. A eclipse of the moon can occur only at full moon.

here you would find it difficult to move about. Instea of jumping over a high wall, as you could do on th moon, you would be lucky if you could jump 3 inche from the sun's surface. A man who weighed 11 stone o the earth would weigh nearly 2 tons on the sun, *provide a spring balance specially designed for heavy weights wa used.* If an ordinary weighing machine was used, th man would be balanced with 11 stone, because, althoug

ıe weighs 28 times as much as this, the same is true of he 11 stone.

Time Required for Light to Reach Us. The sun is ıever exactly where we see it, because the light takes an ppreciable time to travel to the earth. The speed of ight is 186,000 miles each second, and in the case of the ıoon less than $1\frac{1}{2}$ seconds is required for the light to each us, but in the case of the sun the time is about minutes. The nearest star is so far away from us that he light from it takes about $4\frac{1}{3}$ years to reach the earth. Vhen we look at the sun at any time we see it where it vas 8 minutes ago. In certain astronomical computa-ions—for example, in finding the path in which a comet ıoves round the sun—it is necessary to make corrections or the "light-time," and before doing so the distance f the comet from the earth must be determined. When ıis has been done we are then able to make the necessary orrections and to find the path of the comet accurately. Vithout such corrections small errors would be intro-uced into the work. Such are some of the refinements in stronomical investigations.

Questions

1. Give the following established facts with reference to the sun:) its distances at the beginning of January and July, (*b*) its mean dis-ıce, (*c*) its diameter, (*e*) its mass, (*f*) the temperature of its surface.
2. From surface markings, such as sunspots, it is known that the ın's rate of rotation is not the same all over its surface. What onclusion would this suggest to you?
3. What is the cause of sunspots? State briefly what effect they ave on the earth.
4. What is the greatest number of eclipses of both the sun and the oon which can occur in a year?
5. On August 1, 1943, the moon was in the plane of the ecliptic, nd new moon occurred on the same day. What interesting pheno-enon took place?
6. On August 15, 1943, the moon was again in the plane of the liptic and full moon occurred on the same day. What happened?
7. Find to the nearest second the time that light takes to travel om the sun to the earth on January 2 and July 4, 1944, the dates hen we are nearest to and at the greatest distance from the sun.
8. Compare the results in 7 with the times which an aeroplane ving at the rate of 3 miles a minute would require.
9. If the distance to the nearest star is 4·3 light-years, how many iles is the star away? (A light-year is the distance travelled by ght in one year.)

CHAPTER IV

THE SUN'S FAMILY OF PLANETS

Mercury

Mercury Has no Atmosphere. The earth is only one out of a family of nine planets which belong to our solar system—that is, which move in orbits round the sun in a similar manner to the earth. Besides the nine chief planets there are thousands of very small planets, known as the asteroids or minor planets, but few of these can be seen without the help of a fairly powerful telescope. They will be considered in the next chapter.

The nearest planet to the sun is Mercury, and it is also the smallest of the nine planets. Its diameter is only 3,000 miles, which is half as much again as that of the moon. We saw that the moon had not got an atmosphere, and the same thing is almost certainly true of Mercury. On the moon the velocity of escape is 1·5 miles a second, and on Mercury it is a little more—2·4 miles a second—so if there were an atmosphere on Mercury it seems that it would have more chance of being held by the planet's attraction than in the case of the moon. But the temperature of Mercury is much higher than that of the moon, and for this reason the gases composing the atmosphere would be more likely to escape, because the speed of the molecules increases as the temperature increases. We may take it as almost certain that Mercury has not got an atmosphere, and hence that no life exists there.

Elliptical Orbit of Mercury. We saw that the earth is not always at the same distance from the sun; the same is true of Mercury. In fact there is a much bigger difference between the greatest and least distances of Mercury than there is with the earth. Mercury comes to a distance of 28½ million miles from the sun at one time and goes out to a distance of over 43 million miles 44 days later (the planet takes 88 days to make a revolu-

on round the sun), and as a result of the large difference its distances from the sun there are great changes in its rface temperature. Unlike the earth, which rotates n its axis in 24 hours, and so enjoys the succession of ay and night everywhere, the planet Mercury always rns the same face to the sun. If there were people on lercury, those on one side would never enjoy sunshine, nd those on the other side would never lose sight of the n. It would be very trying to live there in perpetual ght, but worse still to live in perpetual darkness. This ould not be the only inconvenience. On the sunny side, you were nearly under the sun, as people are on the rth near the equator, the temperature would be nearly 0° C. when the planet was at its greatest distance from e sun, but when it made its nearest approach the mperature would be as high as 400° C. or even higher. eanwhile people on the dark side would suffer the most tense cold, far beyond anything we have ever endured the coldest place on the earth. Perhaps it is just as well at there is no life on Mercury. Conditions are some-nes hard enough on our own planet, but they would be finitely worse on Mercury.

Mercury Invisible by Night. You can see some of the anets at midnight, or indeed at any time of the night, t you will never be able to see Mercury at such hours. ne planet is never far away from the direction in which see the sun, and hence is lost in the glare of the sun's ht unless a telescope is used. If you knew exactly here to set your telescope during the day you would be le to pick the planet out, in spite of the light of the sun; t this is very difficult, and we do not recommend nateurs to search for Mercury, especially as there is not ry much detail that can be observed with a small escope.

Venus

Resemblances between Venus and the Earth. The next anet as we go out from the sun is Venus, which is very e the earth from the point of view of size and mass. nus does not behave like Mercury in approaching the n much closer at one time than at another; in fact the

orbit is nearly circular. The greatest and the leas distances of Venus from the sun are 67½ and 66½ millio miles, and the time required to complete a revolution 224 days. The diameter is 7,600 miles and the mea density 5·21. So you will see, by comparing thes figures with those given for the earth, that there is a clos similarity between the two planets. Even in their masse this likeness holds, as you would infer from their dia meters and densities. The mass of Venus is abou four-fifths that of the earth, and gravity is nine-tenths c gravity on the earth. The velocity of escape is 6· miles a second—just a little less than on the earth—so might be expected that Venus would be able to hold a atmosphere.

Observation shows that the planet has an atmosphere but not of the same composition as our atmosphere. It is remarkable that, so far as we know at present, there is neither oxygen nor water-vapour on Venus, but there is carbon dioxide in abundance. No definite decision ha yet been reached about the period of axial rotation Some think it is 224 days—the same as the time c revolution round the sun—and others believe that it is about the same as our earth's period. It may seem remarkable to some that astronomers cannot fix thi period more definitely, but there are good reasons for th uncertainty.

Venus Surrounded by a Permanent Cloud. If you eve get the chance of looking at Venus through a telescope do not lose it. You may see the planet when it is crescent like the moon, and this is a beautiful sight. Yo may see her when she is more like a full moon, an probably you will be disappointed with the view. Th reason why the planet appears as a crescent and goe through phases something like the moon is because, lik the moon, Venus sometimes comes between the sun an the earth, and in such cases we see only a slice of th illuminated surface. At other times she is, like Mercury on the side of the sun remote from the earth, owing t the journey of the planet round the sun; the illuminate portion is then turned towards us, and we see her like full moon. The disappointing thing about Venus is tha

t is quite impossible to see the surface of the planet ecause of the layer of cloud which always surrounds er. When the cloud clears a little, as it does very ccasionally, the eye can detect nothing on the *surface*; nly badly defined shadings are seen, and these are almost ertainly in the atmosphere. Of course, if there were lear markings and regular observations were carried ut, it might be possible to determine the time of rotation, ut up to the present this has not been accomplished ith any degree of certainty.

Venus is a morning or evening star and, like Mercury, annot be seen all the night. Under the most favourable onditions she can set in our island about four and a alf hours after the sun. She is an evening star when he sets after the sun, and a morning star when she sets efore the sun.

Vegetable Life Possible on Venus. The temperature on enus is not inconsistent with the existence of life there. n the sunlit face the temperature is between 50° and 0° C., and on the other side it is about —20° C. The st temperature is lower than we are generally accustomed o on our earth during the night, but life is very adaptable, nd it could certainly survive under such conditions. Vhat the nature of the life may be, if there is any at all, it difficult to say, and we can only speculate on the subject. he figures for the temperatures refer to the atmosphere self, because it is impossible to measure the temperature eneath it; but, just as a greenhouse traps the heat of ne sun and becomes warmer, so the surface of Venus as probably a higher temperature than is measured in er atmosphere. If the atmosphere is moist and warm ear her surface there may be some form of vegetable life, ut animal life, such as we know it, is not very likely. s so many of the factors on which life depends are nknown to us, much of this is pure guesswork.

The Earth

Proceeding outwards from the sun, the next planet is the rth. As we have already dealt with it in the opening napter, nothing more will be added, and we shall pass n to Mars, which is the next planet beyond the earth.

Mars

Temperature of Mars. The planet Mars is the most interesting of all the sun's family in one respect—it is probably the abode of life, and this life may possibly be of an intelligent form. Mars is smaller than the earth and its density is less than the earth's, so it is not such a massive planet as our own. It moves in an orbit round the sun at distances which vary from nearly 155 to 128 million miles. We have already explained that the earth's distances from the sun vary from about 94½ to 91½ million miles, and hence, when the earth and Mars are on the same side of the sun, the planet can be as close to us as 34 million miles or as far away as 63 million miles. When the two planets are on different sides of the sun the distance can be as great as 250 million miles.

The diameter of Mars is 4,200 miles, the density 3·9, and its mass just over one-tenth that of the earth. Its surface gravity is 0·38 of the earth's gravity and the velocity of escape is 3·2 miles a second. This is perilously near the "danger line" for ordinary gases which compose the atmospheres of the smaller planets, and perhaps we should not be surprised if Mars had no atmosphere. Actually it has an atmosphere, but its amount is very much less than we have on the earth, so life there, assuming that there is such, would probably take on forms rather different from those to which we have been accustomed.

The planet moves round the sun in 687 days and rotates on its axis in 24 hours 37 minutes, so it enjoys alternation of day and night almost in the same interval as we do. We should expect to find that the temperature on Mars was lower than that on the earth, owing to its greater distance from the sun, and in fact its temperature is much lower. Owing to the scanty atmosphere and the consequent absence of the blanketing effect in trapping the sun's heat like a greenhouse, the nights on Mars must be very cold. Near equatorial regions it has been found that a temperature far above the freezing point of water—perhaps as high as 30° C.—exists, but at sunrise it is as low as −10° C., and during the night it is supposed to fall to −90° C. The temperature at the polar caps has

een measured and found to be as low as —70° C., but s this refers to the cloud layer above the cap, it is possible iat the actual temperature of the cap itself may be igher. We are accustomed to think of the polar caps as mmensely thick, and indeed so they are on the earth, ut on Mars they are only a few feet thick or even less. his is an important matter in view of the fact that some ave believed canals were constructed on the planet to rigate the arid parts by conveying the water from the oles when the caps melted during the summer on each emisphere. We shall return to this point later in the iapter.

Atmosphere on Mars. If you ever look at Mars rough a telescope you will notice that it has very little semblance to Venus. Some parts of the planet appear ddish-yellow and others are bluish-green, and the latter e suggestive of seas—a title which the early observers estowed on these areas. This view is no longer held, id it is thought that they may be some form of vegeta-on. The general ruddy colour of the planet has been tributed to the rocks, which have taken most of the xygen out of the atmosphere, the oxidized rocks ppearing red. In contrast with these the rocks on the oon look grey or brownish because they were unable combine with oxygen, the moon being devoid of an mosphere. Support is lent to this view by the fact that e amount of oxygen in the atmosphere of Mars is very iall, but it may have had an abundance of this gas fore the rocks absorbed it. How far the present pply is capable of supporting animal life is a question iich it is impossible to decide. We are disposed to dge the conditions necessary for life from our own nited point of view, and hence assume that animal life ould be impossible without an amount of oxygen mparable with the quantity existing in our atmosphere. iis may be so, but there is no proof that it is, and there ems no fundamental obstacle to animal life—perhaps in more intelligent form than we find on the earth—existing Mars. There is almost certainly vegetable life there.

Surface Markings on Mars. We have already spoken out the " canals " on Mars, which some have held to

be made with the object of carrying water to the dr regions of the planet. It would require too much spac to discuss this matter fully, but it may be briefly sum marized by saying that the notion of artificial canals, s strongly held by the late Professor Lowell and others, i now discredited. They are surface markings which th eye often interprets as continuous lines, althoug continuity does not always exist, and experiments hav shown how easy it is for the eye to misjudge certai details.

Here is an experiment which you can try for yoursel Draw a number of dots on a piece of paper, say abou five to the inch, and make them large enough to be see about 30 feet away. Now ask someone who does nc know that they are dots to stand about 30 feet from ther and to tell you what he sees. You will find that he wi probably say he sees a line, but if you show him the dot first of all he will almost certainly interpret them as dot even at a distance. For the same reason, markings o Mars which appear continuous are not necessaril continuous, and it is practically certain that som eminent astronomers have been misled by appearance Of course, the absence of the so-called canals does nc necessarily imply that intelligent life is non-existent o Mars. Perhaps if it does exist there it does not fin equatorial regions so arid as some have thought they ar —at least not too arid for life which has accommodate itself to its environment.

Satellites of Mars. Mars has two moons or "sate lites," which is the usual term for these bodies. They ar very small, the greater of the two, Phobos, having diameter about 10 miles. It revolves round Mars at mean distance of 5,828 miles in 7 hours 39 minutes. Th smaller satellite, Deimos, has a diameter about half tha of Phobos, and revolves round Mars in 30 hours 1 minutes at a mean distance of 12,475 miles. Thes satellites, like the majority of those in the solar systen revolve in the same direction in which the planet rotating. A curious effect is produced in the case c Phobos. Its period of revolution is about one-third th period of rotation of Mars, and hence this satellite, a

een from the surface of the planet, rises in the west, moves eastward, and sets in the east. Deimos does not act n the same way, because its period of revolution exceeds he period of rotation of Mars; and it rises in the east nd sets in the west, just like our own satellite, the moon.

Jupiter

Dimensions and Atmosphere of Jupiter. Outside the rbit of Mars there are the asteroids to which we have eferred in the early part of the chapter. As they are ery small we shall pass them by for the present and look t the next planet out from the sun, the largest of them ll, the planet Jupiter.

Jupiter revolves round the sun in a period a little under 2 years, and his distances from the sun vary from over 06 to 460 million miles, the mean distance being 483 illion miles. The density is only 1·34, so that the lanet weighs only one-third more than an equal volume f water. Jupiter rotates on his axis in 9 hours 55 inutes—a very short time for such a large body—and s a result of this rapid rotation there is considerable attening at the poles and a bulge at the equator, which an be easily detected with a small telescope. The iameter of Jupiter at his equator is 88,700 miles and his olar diameter is 83,800 miles; these figures show a con- derable flattening at the poles. We have seen that the ifference between these two diameters in the case of our arth is 26 miles, but with Jupiter it is nearly 5,000 miles. n spite of the fact that the planet is over 1,300 times the ze of the earth, its weight is only 318 times that of the arth, the apparent discrepancy arising from the low ensity of Jupiter. It is believed that the height of the tmosphere is a very great fraction of the planet's dius, and this view explains the disparity in the densities f the earth and Jupiter. Some authorities have thought at Jupiter's atmosphere is about 6,000 miles thick, but ere is considerable doubt if it is actually as thick as this. is also believed that outside the central rocky core which has a diameter about half that of the planet) ere is a layer of ice thousands of miles thick. It is rtain that there is no evidence of internal heat in

Jupiter, and the greater part of the radiation which he sends out is only reflected sunlight. The temperature o the atmosphere is about —130° C.—which is not very suitable for life in higher forms such at least as we know on our planet. Even if the temperature was congenial to life the atmosphere is very unlike anything of which we have experience. It consists mainly of ammonia and methane (or marsh gas), the latter occurring on the earth in marshy places by the decomposition of vegetable matter. If you disturb the bottom of a pond the bubbles of gas which rise to the surface consist chiefly of marsh gas. As you probably know, it is also found in large quantities in coal mines.

The markings on Jupiter are not so permanent as those on Mars, and we should expect this because what we see is mainly atmosphere, not the solid crust of the planet. Just as the sun has different rates of rotation at different latitudes, so Jupiter shows the same characteristics. We have already spoken of his period of axial rotation as 9 hours 55 minutes, but in the equatorial zone it is 5 minutes less than this, and so any particular features close to the equator gain on those which are north or south of this line.

Surface Features of Jupiter. A small telescope shows a few dark streaks—the *belts*—which are parallel to Jupiter's equator. When a large telescope is used these belts exhibit a very large variety of detail and rapid changes of form. Of course such changes would not occur on a solid surface, and what is seen is something moving in the planet's upper atmosphere. The most conspicuous of the belts are the *north and south equatorial belts*, which are about 10° on either side of the equator and include the bright *equatorial zone* within their boundaries. Beyond the equatorial belts are the bright *north and south tropical zones*, and beyond these there are less conspicuous belts and zones until we come to the polar regions. The study of the Jovian features has been the life work of some astronomers who have specialized on this subject, but in spite of all their work there is still much that we do not know about the planet, but which future observers will no doubt be able to explain.

Satellites of Jupiter. When you look at Jupiter with a mall telescope you will be struck with the beauty of the atellite system. Four out of the eleven satellites which ttend the planet are visible in the smallest telescope; hey were discovered by Galileo in 1610 with his home-nade telescope. They move in nearly circular orbits ound Jupiter and also very close to the plane of his quator, which is near the plane of the ecliptic. When ou see them through a small telescope, or even through pair of good binoculars, they appear just like faint tars close to the planet. They may all be on one side or hey may be on different sides of Jupiter, because they ll have different periods of revolution round the planet, nd so are seen in various positions with regard to their arent. These satellites move with great regularity, nd it is possible to predict exactly where any one of them ill be at a certain time. Just as eclipses of the sun and noon can be predicted, so the eclipses of Jupiter's atellites can be predicted too. These eclipses occur hen a satellite moves into the shadow thrown by upiter in the same way as the moon is eclipsed when she noves into the shadow thrown by the earth, the sun's ght being intercepted in each case.

In 1675 the Danish astronomer Roemer noticed that he observed times of eclipses occurred earlier than the redicted times when the earth was nearer Jupiter than he average, and also that the reverse occurred if the earth as at a greater distance from Jupiter than the average. efore his time it was known that predicted and observed mes did not agree, but no adequate explanation was rthcoming until he pointed out that light did not travel ith an infinite velocity, as was believed prior to his days. hen the earth was nearest to Jupiter, light would not ave so far to travel, and so the eclipse would appear rlier than was expected. On the other hand, when the rth and Jupiter were as far apart as possible, the light ould have a greater distance to travel and the eclipse ould be seen after their predicted times. This discovery forded one method of measuring the speed of light. ee Fig. 7).

The name of the four largest satellites of Jupiter are

Io, Europa, Ganymede, and Callisto. The last two ar the largest, having diameters over 3,000 miles, which i

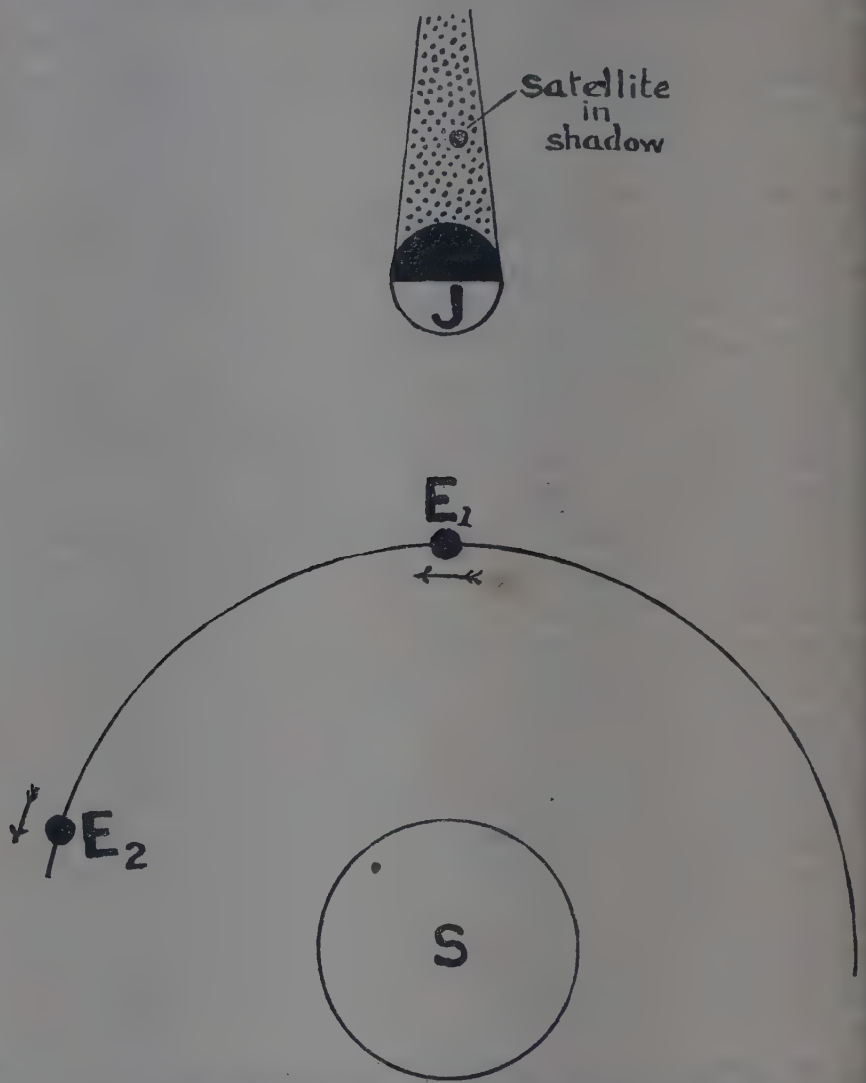


FIG. 7.—The diagram shows the shadow cast by Jupiter, and or of his satellites in the shadow. When the earth is in positio E_1 the eclipse of the satellite will be observed sooner tha when the earth is in position E_2. This is due to the fact tha the distance from E_1 to Jupiter's satellite is less than that fro E_2 to the satellite, and hence the light takes longer to travel t the earth in the latter case.

half as large again as the diameter of our satellite Eight of Jupiter's family of satellites have "direct motion—that is, they move round their parent in th same direction in which he, in turn, moves round th

un. Three have "retrograde" motion; they move ound Jupiter in the opposite direction to which he moves ound the sun. Very important problems are raised by etrograde motion, which, as we shall see, occurs in some ther cases as well, but it is beyond the scope of this work o discuss these.

Saturn

Saturn the Least Dense of all Planets. Saturn is the ext planet as we journey out from the sun, and it ranks ose to Jupiter in size, though not in mass. Its quatorial and polar diameters are 75,000 and 67,000 iles respectively, and its rotation period is 10 hours 4 minutes. The rapid speed of rotation accounts for ie differences in the two diameters and, as with Jupiter, ie polar compression or flattening can be clearly seen rough a small telescope.

Saturn's greatest and least distances from the sun are 31 and 841 million miles respectively, the mean being 86 million miles. To complete a journey round the sun quires nearly 29½ years. It has the least density of all e planets, being only seven-tenths the density of water. is startling to realize that if Saturn could be placed in n enormous ocean it would float; it is the only planet at could do so. As its density is so low it follows that ost of what we see of Saturn is simply its atmosphere. is believed that it resembles Jupiter in this respect, and at, underneath an extensive atmosphere—which, like piter's atmosphere, is composed of ammonia and ethane—there is a thick layer of ice, and underneath is a rocky core. The clouds are arranged in bands, they are on Jupiter, but the bands are much less stinct (which is not surprising in view of the planet's eater distance), and they do not appear to change eir shape so rapidly. Underneath the envelope of ouds the planet itself is wrapped in mystery, and we can ly guess about its physical condition.

If Saturn itself does not present many attractive atures, the same cannot be said about its system of ngs, which we shall now describe.

Saturn's Rings. There is no more beautiful sight in all e heavens than the rings of Saturn, and no one should

miss an opportunity of looking at them through telescope. A small telescope of about 3 inches apertu will show them, provided they are well placed f observation. The ring system is 171,000 miles acro and is made up of a dusky ring, an inner light ring, and a outer light ring.

About 7,000 miles from the equator of Saturn tl crape or dusky ring begins, and it extends for 11,5(miles, after which there is a gap of 1,000 miles between and the inner bright ring. The inner bright ring 16,000 miles across; beyond it there is another gap (Ca sini's Division) under 3,000 miles wide, and then v come to the outer bright ring, the width of which 10,000 miles. It will be seen from these figures that t total width is 41,500 miles, but if to this is added 7,0 miles—the distance of the crape ring from the surface the planet—and then to this 37,500 (the radius Saturn), we find that the far edge of the outer bright ri is about 86,000 miles from the centre of the plan Hence, if we measure across from one extremity of t rings to the other, the distance is about 171,000 mil though of course only 82,000 miles of this consists of t rings. The thickness of the rings is probably about miles, but it is impossible to be very definite about th and it may be more than 10 miles, but is almost certain less than 50 miles.

When the rings are so situated that their broadside partly towards us we see them better than when they a turned edge on. In fact, in the latter case they disappe almost completely and look like a narrow bright lin You can illustrate this by taking a piece of cardboard c which light is shining and turning its broadside towar you. It will be seen easily at some distance but will n be so visible if the edge is turned towards the observer.

Nature of the Rings. When we speak of Saturn rings the term is slightly misleading because we general think of a ring as something solid. But Saturn's rin are not solid; they are composed of myriads of sma bodies, some as small as dust particles and some probab the size of a cricket ball, but none of them large. Ho did they come to be where they are, every small bod

pursuing its own orbit round the planet, just as the planets pursue their own orbits round the sun? There is no reason why they should not continue to follow their present orbits for thousands of millions of years, but there was a time when conditions were very different. It is fairly certain that when we look at this beautiful ring system we see the fragments of a former satellite whose eagerness to cultivate too close an acquaintance with the planet was its own undoing. Once it was moving round Saturn as the moon moves round the earth or as Saturn's other satellites still describe their orbits round the planet. It came, however, too close to the planet, with disastrous results. There is a law in celestial mechanics that it is dangerous for bodies to come too close together. Like relatives who live apart, peace may be preserved so long as plenty of space intervenes, but if the space narrows, trouble may arise. So with celestial bodies; if they venture too close together the smaller will be torn into pieces by the larger and more massive body. At some time a small satellite must have gone into the danger zone near Saturn, and we see the results of this step in the fragments composing the rings. The sight of the rings is so wonderful that no astronomers have ever been heard to express any regrets at the fate of the little satellite whose expedition too close to its giant companion ended in its destruction.

Saturn's Satellites. Of Saturn's nine satellites the sixth in order from the planet is Titan, which is the largest of them all. Its diameter is 3,550 miles and its mean distance from Saturn is a little over 759,000 miles. It requires 16 days to move round Saturn. The next in size is Rhea, the fifth in order from Saturn, with a diameter of 1,150 miles. The diameters of the others are all under 1,000 miles. The satellites of Saturn revolve in direct orbits, except the outermost one—Phoebe—which is over 8 million miles away from its planet and completes a revolution in 550 days.

URANUS

Uranus was discovered accidentally in 1781 by Sir William Herschel when he was observing a region of the

sky in the constellation of Gemini with his 7-inc reflecting telescope. At first he thought it was a come In those days no one expected to discover a new plane and several months passed before astronomers were su that a new world outside the orbit of Saturn had bee found.

Uranus has a year which is 84 of our years; that is, th planet takes 84 years to complete a circuit round the su The average distance of the planet from the sun is 1,78 millions of miles, which is 19 times the distance of th earth. Its diameter is 31,000 miles, and it rotates on i axis once in 10 hours 48 minutes. Its density is 1·36- just a little greater than that of Jupiter. The atmospher consists chiefly of methane; large telescopes sho belt-like markings which are probably of the same natur as are those of Jupiter and Saturn. There are fou satellites attending Uranus, and their revolution as we as the rotation of the planet has certain interestin features. Generally speaking, satellites revolve in orbi which are not very far from the plane of their planet equator. The plane of a planet's equator is usually nc inclined at a great angle to the plane of the ecliptic. I the case of the earth this angle is $23\frac{1}{2}°$. For Mars it nearly the same, while it is very small for Jupiter. Th plane of the equator of Uranus is, however, nearly a right angles to the plane of the ecliptic, and as th satellites revolve close to the plane of the planet' equator, their orbits are nearly perpendicular to th ecliptic.

You will be fortunate if you see Uranus with th naked eye, as it is just on the borderline for vision withou optical aid. Unless it is viewed through a large telescop no details of its surface features can be seen. Eve through a large telescope its satellites appear so sma that it is impossible to measure their diameters.

Neptune

Neptune revolves round the sun once in 165 years at mean distance of 2,793 millions of miles. Its day is 1 hours 40 minutes in length, but it is practically certai that there is no form of life on the planet to enjoy da

and night. Its temperature has not been measured directly, but as it is much farther from the sun than Uranus, the temperature of which has been found to be −180° C., we may be certain that the planet is colder than this and, like Uranus, incapable of sustaining life. Its atmosphere is similar to that of Uranus, consisting largely of methane.

The diameter of Neptune is 33,000 miles and its density is 1·32. It is attended by one satellite, named Triton, which revolves with retrograde motion. Very little is known about the surface features of the planet. It is invisible to the naked eye.

Pluto

Pluto was discovered on March 13, 1930, not accidentally but as a result of a long and systematic search for a planet beyond Neptune. Mr. Clyde Tombaugh, at Lowell Observatory, while examining photographs taken in January of 1930, detected the planet on the plate.

It revolves in an orbit at a mean distance of 3,670 million miles from the sun, completing one revolution in 248 years. This orbit is very eccentric and the distances from the sun vary from 4,587 to 2,752 million miles. Comparing this last distance with that of Neptune it will be seen that at times Pluto is actually closer to the sun than Neptune, though at other times it is half as far again from the sun as Neptune. Nothing is known about its period of axial rotation, and its satellites, if it has any, would be very much too small to be visible. It is difficult to measure its diameter, but the planet is probably about the size of Mars.

Questions

1. Why do you think that Mercury has not got an atmosphere?
2. Explain why great contrasts occur in the temperature of Mercury.
3. Why is it impossible to see Mercury a long time after sunset?
4. What is the chief gas in the atmosphere of Venus? What kind of life would you expect with such an atmosphere?
5. Explain why Venus sometimes appears as a crescent and sometimes like the full moon.
6. Why would you expect the atmosphere on Mars to be very thin?

7. What are the "canals" on Mars?
8. Is there any explanation of the ruddy appearance of Mars
9. What interesting facts do you know about Phobos, and wh phenomenon would people on Mars see in connection with th satellite which we do not see in the case of the moon?
10. Explain the polar flattening and equatorial bulge on Jupite
11. What would you infer about the atmosphere of Jupiter fro the fact that the density of the planet is so small?
12. Why would it be impossible for life, such as we know it, exist on Jupiter?
13. How have Jupiter's satellites been used to measure the spe of light?
14. What is there unique about Saturn?
15. Give a description of Saturn's rings. Of what are th composed?
16. Why are the rings sometimes invisible?
17. What is the past history of the rings?
18. Who discovered Uranus, and how was he mistaken about t planet?
19. What is there peculiar about the satellites of Uranus?
20. What do you think about the possibilities of life on Neptun
21. When was Pluto discovered? What is its mean distan from the sun?

CHAPTER V

THE ASTEROIDS, COMETS, AND METEORS

Discovery of the Asteroids. Between the orbits of Mars and Jupiter there lie an immense number of small bodies of various sizes, all moving in different orbits at various distances from the sun. These bodies are known as the *asteroids*, or *minor planets* or *planetoids*. Only one of them—Vesta—can be seen with the naked eye, and as far as appearances go these bodies are of little interest. Nevertheless they present problems of great importance to astronomers, and so something must be said about them.

The first to be discovered is called Ceres, and its discovery by Piazzi, in Sicily, on January 1, 1801, was quite accidental. Pallas was discovered in the following year by Olbers. Two more, Juno and Vesta, were discovered in 1804 and 1807 respectively, and then a long interval passed before any others were detected. An amateur astronomer, Hencke, searched for 15 years in the hope that he would be able to find more minor planets, and in 1845 his efforts were rewarded by the discovery of the fifth of these small bodies. Every year since 1847 has added to the list, and at present there are over 2,000 of them known. Search for them is now conducted by photography. There must be scores of thousands of them which have not yet been found, but probably the larger ones have all been discovered.

The diameter of Ceres is 480 miles, and Pallas, the next in size, has a diameter of 300 miles. Most of these bodies are less than 50 miles in diameter and the majority are very small—some of them only a few miles across. They do not all move close to the plane of the ecliptic like the other planets, and their orbits are often very flat ovals. One of them, Hidalgo, is nearly five times as far from the sun at the greatest as at the least distance, and the inclination of the orbit to the plane of the ecliptic

is 43°. A few of the asteroids have come very close to th earth, but there is only a very remote possibility of collision ever occurring.

Origin of the Asteroids Unknown. There is a certai similarity between the asteroids and Saturn's rings, thoug the asteroids are greatly outnumbered by the bodie making up the rings. The similarity does not mean tha the asteroids were formed in the same way as the ring In fact the asteroids are not close enough to Jupiter– their nearest big neighbour—for disruption to have bee caused by his attraction. Nevertheless, it is fairl certain that the asteroids were caused by some celestia catastrophe, but the nature of the catastrophe is doubtfu Professor K. Hirayama of Tokio showed that th asteroids could be divided into five families so far a their orbits were concerned, and that all the asteroids i each family probably came from the same source. Thi would imply that the explosion of a single planet coul not have been responsible for the production. Perhap there was once a single planet which divided before had become solid during its cooling stage; and then eac of these parts suffered from some internal convulsio which broke them to pieces. This is merely guesswork and the astronomer still finds the problem of the origi of these bodies very puzzling.

Bode's Law. Johann Elert Bode, a celebrated Germa astronomer, was born in 1747. From his earliest days h was devoted to the mathematical sciences—astronom in particular. His law * on the distances of the planet from the sun is useful in helping us to remember thes distances, taking the earth's distance from the sun as th " yardstick."

Write down the numbers 0, 3, 6, 12, 24, and so on, eac number after the second being double the one before i Add 4 to each of these and we get a series of figures– 4, 7, 10, 16, and so on—which will give the relativ distances of the planets from the sun, except in the case of the two outer planets, Neptune and Pluto. Th figures are not exact, but they are fairly close. Writin down the numbers according to the directions it will b

* Titius is associated with Bode in formulating the law.

seen from the following table that they correspond closely in many cases to the mean distances of the planets.

Mercury	Venus	Earth	Mars		Jupiter	Saturn	Uranus	Neptune	Pluto	
4	7	10	16	28	52	100	196	388	772	(According to Bode's Law)
3·9	7·2	10	15·2		52	95·4	192	300·7	390	(Actual Distances)

If 10 represents the distance of the earth from the sun, the distance of Mercury should be 4, of Jupiter 52, and so on, so that Jupiter should be 5·2 times as far away from the sun as the earth is, always remembering that *mean distances* are used. The figures in the lower line show the *actual distances*, that of the earth being 10, and they are in good agreement with those computed by Bode's Law, except for the last two planets. When the law was first put forward nothing was known about the asteroids or the three outer planets, and when Uranus was discovered it was found to fit in very well with the scheme. It was noticed that there was a gap at 28, and this convinced many astronomers that there must be a missing planet at that distance, between the orbits of Mars and Jupiter. A society of astronomers was formed to search the heavens systematically for the missing planet. When the asteroid Ceres was discovered it was found to fit in with the distance; the average asteroid fulfills the conditions for the distance 28 fairly well. (See Fig. 8.)

No satisfactory explanation has been given of Bode's Law, but it cannot be considered a mere coincidence in spite of the fact that it does not apply to Neptune and Pluto. Perhaps when we know more about the origin of the planets it will be possible to explain the law.

Comets

Comets Once Portents of Disaster. The appearance of comets in ancient times was usually regarded as an omen of some disaster, and historians were careful to record their appearances. Even in more recent days there have been cases of superstitious dread of these visitors, though

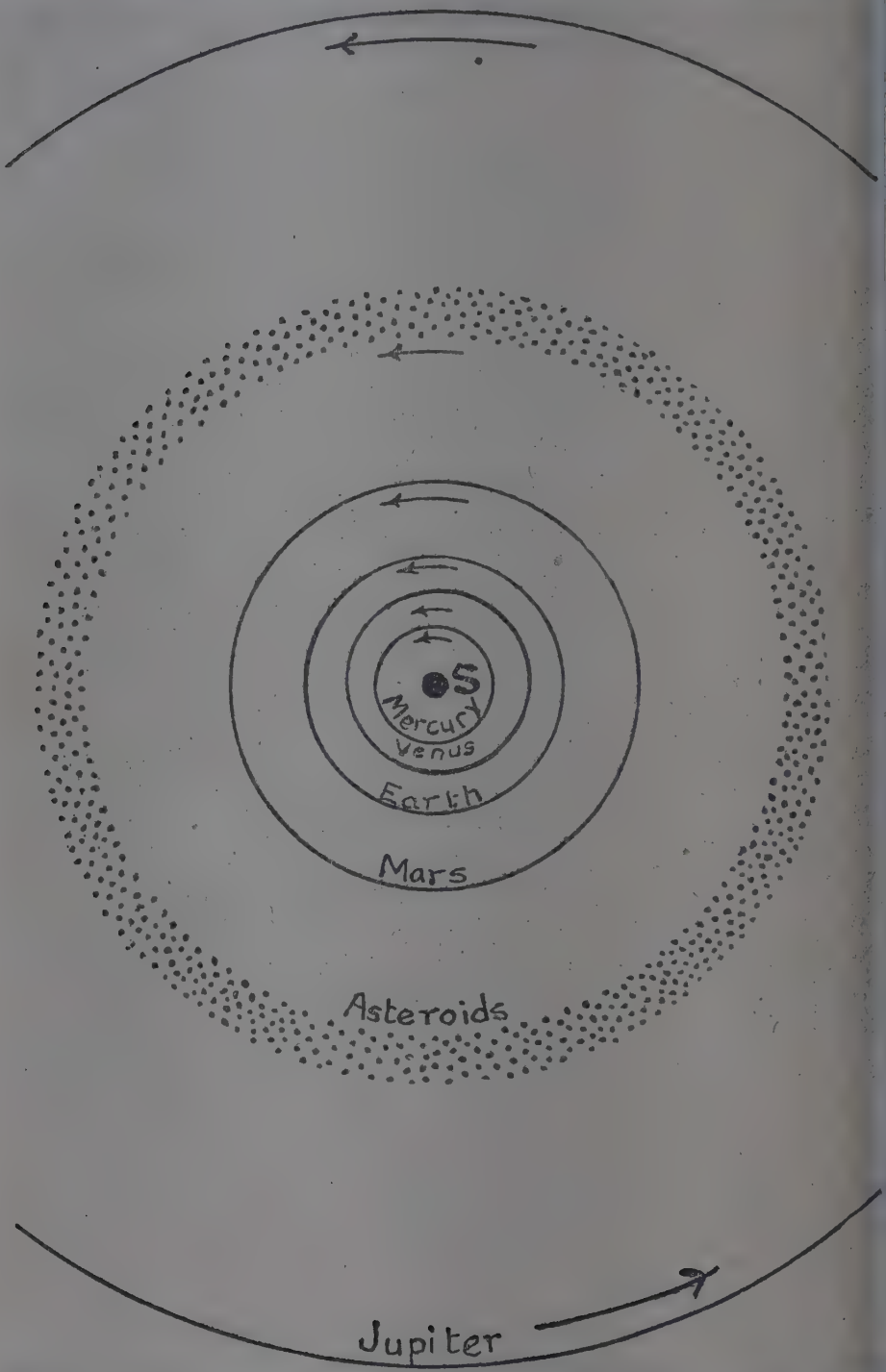


FIG. 8.—Mean distances of the planets Mercury, Venus, Earth Mars and Jupiter from the sun are shown drawn to scale The asteroids are shown scattered about between the orbi of Mars and Jupiter.

superstition has been largely replaced by the more rational fear of a collision with the earth—a fear not utterly baseless, though very often exaggerated. Unfortunately very bright comets are rather rare at present, and by far the greater number of those that come reasonably close to us can be seen only through the telescope. We use the word "unfortunately," because a bright comet is a wonderful spectacle and never fails to arouse awe and admiration in the minds of spectators. The last bright comet that we saw in the northern hemisphere was Halley's Comet in 1910, and it caused a considerable amount of interest in this and other countries.

Comets Members of the Solar System. Comets are no longer regarded as coming from outside the solar system; it is believed that they are members of the sun's family just as much as the planets and asteroids, and indeed the paths which they describe in their motion round the sun are very similar to those of some of the minor planets. In many cases they move in close to the sun and then go out to an enormous distance, taking a long time—often centuries—to complete one revolution. Halley's Comet, about which we have just said something, comes within 55 million miles of the sun at its closest approach and then recedes to the enormous distance of 3,300 million miles 38 years later, completing a revolution in 76 years. None of the planets moves in such an elongated orbit as this, and there are comets which have much more elongated orbits than Halley's.

The planets and asteroids all move round the sun in the same direction, but the comets are quite indifferent about the courses in which they move. Some are almost in the plane of the ecliptic, like the planets; some move at right angles to the ecliptic, and between these extremes others pursue their journey at various angles. Many, again, move in the reverse direction to that in which the planets move, and with different inclinations; taken on the whole, there are less with this retrograde motion than there are with direct motion. All this is very puzzling to the astronomer, who tries to find out how the planets and comets came into their present orbits, and

up till now no one has been able to provide a satisfactory answer. (See Fig. 9.)

Composition of Comets. A comet consists of three distinct parts: the nucleus, the coma, and the tail. The nucleus consists of myriads of small particles varying in dimension from a good-sized house to specks of dust. It is a mistake to think that the nucleus is one solid body; it may contain a number of large solid bodies, and if any one of these struck the earth it would certainly cause some damage. The coma is a foggy-looking disc which surrounds the nucleus and enables us to distinguish the

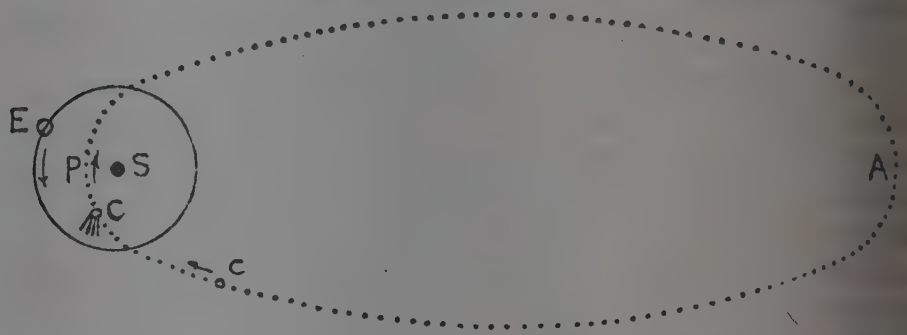


FIG. 9.—The paths followed by a comet and a planet are shown in the diagram, the broken line denoting the comet's path. The planet moves nearly in a circle, while the comet follows an elongated ellipse, coming closest to the sun at *P* and going off to its greatest distance at *A*. Near the sun a comet develops a tail which points away from the sun, as shown. At other parts of its orbit the tail disappears. The comet is moving in a direction opposite to that of the planet. Less than half the comets have this retrograde motion.

comet from a star or a minor planet. The coma varies very much in size, but on the average we may compare it to the size of Jupiter. This is only a rough guide, as the coma may be ten times bigger than Jupiter, or even more. The coma of the great comet of 1811 was a million miles across, but this is rather exceptional. The tail of a comet develops only as the object approaches the sun, but there are comets which never develop tails, and there are others which develop two or more tails. The minute particles composing the tail—very much smaller than those in the nucleus—are driven off from the nucleus by a repelling action of the light of the sun, and this action

eases as the comet comes near to the sun. Some of light by which a comet shines is simply reflected ight, just as we see Saturn's rings by the light of the which the particles reflect. This, however, does not ain *all* the light of the coma and tail. It has been vn that a great part of the light from these portions comet is due to glowing gas. Perhaps we are looking omething which is similar to the glow of the aurora e atmosphere of the earth.

omets' tails are sometimes very long—many millions iles—and the earth occasionally passes through them out suffering any ill effects. This happened on May 1910, when we went through the tail of Halley's et; the tail was estimated to be about 19 million long at the time. The tail is often the most fright--looking portion of a comet, but in fact it is the most less. The nucleus contains the possibilities of uction if it encountered the earth, and though its is very small in comparison with that of the planets, peed at which it would strike us would be responsible erious consequences. It has been estimated that east mass of the nucleus of Halley's Comet was 30 on tons, and it may have been much greater than this. ere has been much speculation about the origin of ts. Were some of them ejected by the larger ts, Jupiter and Saturn especially? Were they vn out by the sun at a time of great activity on his ce? Are they the remains of debris which was torn of the sun by a passing star and most of which ensed to form the planets? Are they visitors from de the solar system? We can answer the last ion now in the negative, but still we do not know e they came from, and it must be left to posterity ve the problem.

Meteors or Shooting Stars

ne Meteors are the Debris of Comets. There is a connection between meteors and comets. This is ated in the case of Biela's Comet, which revolves the sun in a period of $6\frac{3}{4}$ years. It was observed it into two parts when it made its return near the

earth in 1845, and at its next return in 1852 these two parts had separated much more. The comet should have returned again at the end of 1858, but it was not seen, and actually it was not very well placed for observation. Conditions for seeing it were more favourable in 1866 but again it was not observed. In 1872 it "appeared," in the form of a most wonderful display of meteors, on the night of November 27, and this shower has been repeated since at about the same date, sometimes as a considerable shower, sometimes as only a very feeble display. The debris of Biela's Comet had thus provided the material for producing a shower of meteors or shooting stars.

Size and Velocity of Meteors. Meteors are very small particles—most of them about the size of grains of sand—which are moving in orbits round the sun like the comets, and encounter the upper regions of the atmosphere in their motion. Their speed is about 26 miles a second, and as the earth is moving at a speed of 18 miles a second, it is possible for these bodies to enter our atmosphere with a speed of about 45 miles a second if they meet the earth direct. If, on the other hand, they are following the earth, the speed with which they strike the atmosphere will be the difference between 26 and $18\frac{1}{2}$—that is, $7\frac{1}{2}$ miles a second. In this case the earth's attraction hurries them on a little, and the actual speed is about 10 miles a second. Between the extremes of 45 and 10 there are intermediate speeds with which they enter the upper atmosphere, depending on the direction in which they are moving with reference to the earth. Their speed is responsible for their destruction. Friction with the atmosphere raises the molecules to a very high temperature, and the tiny bodies are rapidly burnt out, a flash of light informing us of their destruction. The heights at which they appear and disappear vary according to their speed and size, but generally they are seen first at a height of about 70 miles and disappear when they are 40 miles from the surface of the earth.

It must not be assumed that all the meteors which we see are the debris of comets, though there are several well-known meteor showers which are definitely associated with comets, some of which are still in existence and some

(like Biela) quite defunct. An expedition organized some years ago by Harvard Observatory, U.S.A., to study meteors from observations made in Arizona, was responsible for certain views about these bodies being modified. It was found that most of them were moving much more rapidly than had been previously assumed, some as fast as 120 miles a second. Such a high velocity would imply that they were not members of the solar system but came from outside space. These results did not include those meteors which are accepted as associated with comets, but they included the great majority of meteors. In the last few years, however, much doubt has been expressed, with very good reasons too, on the validity of the results of this expedition. It is probable that most meteors are moving in orbits round the sun, and so are members of the solar system, though only a comparatively few of the well-known showers which occur about the same period each year are due to the debris of comets.

Meteorites

Occasionally some of the meteors are fairly large and are not completely burnt up by the heat which they generate in the atmosphere. In these circumstances the bodies or fragments of them rush through the atmosphere, sometimes with a loud noise and a strong light, and strike the earth. It may seem surprising that they do not penetrate the ground deeply, considering the high velocity with which they enter the atmosphere, but the resistance of the air reduces their speed very quickly. We do not witness the fall of many of these meteorites in a small country like England, but in America there are numerous records of the phenomenon, and there are many collections of the fragments of these bodies in the museums. Occasionally a meteorite of enormous size strikes the earth with great force and leaves a crater. In Arizona, near Cañon Diabolo, there is a crater in the desert, 570 feet deep and 4,200 feet in diameter, which is almost certainly due to the impact of a meteorite. Within a radius of 6 miles from the crater small pieces of meteoric iron, weighing several tons, have been collected,

and these pieces were evidently once associated with th great mass which now lies buried in the earth. It uncertain when the meteorite fell, but as cedar tre 700 years old are growing on the rim of the crater th event must have taken place before they started the growth. From the weathering of the rocks it is believe that the fall could not have been more than 5,000 yea ago, and it may have been at any time between thes extreme limits.

A very large meteorite fell in a forest in north centr Siberia on June 30, 1908, and devastated an area 3,000 or 4,000 square miles. The trees were blown dow by the blast and lay with their tops pointed away fro the centre of the area. This meteorite must have broke up before impact, or perhaps it consisted of a number large bodies moving close together, because many crate have been discovered in the neighbourhood, the large about 150 feet in diameter.

If any of these large meteorites fell in a populo district there would be terrible destruction of life, b fortunately such falls are very rare.

Questions

1. In what respects do the asteroids differ from the planets?
2. Why do you think that the asteroids were not formed in t same way as Saturn's rings?
3. State Bode's Law and show how it has been useful in findi planets.
4. What is a comet? If comets are dangerous, wherein dc their danger lie?
5. In what respects are comets similar to the asteroids and what special way do they differ?
6. Why is a comet's tail pointed away from the sun?
7. Explain why the coma and tail of a comet shine.
8. What comet broke up and produced a shower of metec which can still be seen in November occasionally?
9. What are meteors? How high are they, on the avera when they appear and disappear?
10. Why do meteors glow and then disappear?
11. Distinguish between a meteor and a meteorite. Which the more common?
12. State what you know about the Arizona Crater.
13. Why would craters formed on the moon by meteorites more likely to survive than those formed on the earth?

CHAPTER VI

THE STARS

Distances of the Stars Expressed in Light-Years. Up to the present we have considered only those bodies which are members of the solar system, whose distances from us are measured in millions of miles or sometimes in the more convenient unit of the mean distance of the earth from the sun. This distance—93 million miles—is a useful "yardstick" or unit of measurement for many astronomical purposes, so long as we keep within the solar system. When, however, we pass beyond the bournes of our own little system to the so-called "fixed stars," the earth-to-sun unit becomes too small. It is then necessary to adopt the more convenient standard of a "light-year"—that is, we record the distance of the star in the number of years which its light takes to reach the earth. Light travels from the sun to the earth in about 8 minutes. The time required for light to travel from the nearest star to the earth is $4\frac{1}{3}$ years—figures which will give some idea of the immensities of space. One light-year represents nearly 6 million million miles, and a convenient way of expressing this is by writing it in the form 6×10^{12} miles. This is about 66,000 times as far away as the sun is, and it must be remembered that we are now considering the *nearest* star. Later on, when we come to deal with some of the far-off stars, the figures will appear truly staggering.

We have already seen that the planets move round the sun and that this motion can be detected by observing them for a short time against the background of the stars. The slowest-moving planet which is easily visible to the naked eye is Saturn, and if you watch this planet carefully through one month you will notice that it appears to move across the background of the stars for a distance which is about twice the diameter of the moon. On the other hand, you will not find that you can detect the

movement of any star with reference to the others. They all appear to share equally in the movement from east to west, due to the rotation of the earth on its axis from west to east. There is, however, no visible change in their *relative* positions, so we speak of the " fixed stars.' Nevertheless, all these stars in the heavens are in motion —some of them with speeds of several hundreds of miles a second—but they are plunged in the depths of space at such enormously remote distances that only the most delicate instruments of the astronomer can detect their separate movements.

How the Distances of the Stars are Measured. The distances of many of the stars have been measured, and it will be of interest to know how this is done. In a previous chapter a short description was given of the method of measuring the distance of the moon from the earth, and the same method has been employed to find how far the sun is away. In the sun's case, however, there are other ways of determining this distance more accurately, but they are too difficult for beginners to understand. It will be sufficient to recall that a base line and two angles are all that are required to find the other sides of a triangle, and the longer the base line the better the results. Suppose for instance, that we wanted to find how far away a landmark was and that, with a base line of 60 feet, we found the two angles between this base line and the line drawn from the object to each end of the line in turn to be 85° and 94°. The other angle of the triangle would be only one degree, and if we used an instrument which was not very accurate—say a prismatic compass—small errors could easily occur in measuring the angles, which would introduce very considerable errors in our calculations. This difficulty could be avoided by using a more sensitive instrument than a prismatic compass, but even with the most refined instruments there is a limit to the accuracy with which readings can be taken.

The other and more promising method is to increase the length of the base line. Suppose we took a base line of 4,000 miles on the surface of the earth and attempted to use it for finding the distance of the nearest star; it

would be the equivalent of using a base line of 8 feet to find the distance of an object ten million miles distant. Needless to say, no accuracy could be secured under such conditions, and so any distances that we can measure on the earth are useless for finding the distance of a star. There is, however, another line which can be used, and this will now be described.

The earth takes a year to move round the sun, and its mean distance from the sun is 93 million miles. A base line twice this length—186 million miles—is thus provided for the astronomer if he waits 6 months for his observations. Even with such a long base line he must use the most delicate instruments to obtain anything approaching accurate results. The length of this base line compared with the distance of the nearest star is similar to a base line of 1 yard taken to find the distance of an object 26 miles off. This will give some conception of the accuracy which is necessary to obtain reliable results. The whole process of finding the distances of the stars is too involved for a simple explanation, but you can accept the figures as trustworthy, though, of course, allowance must be made for small margins of errors, especially in the case of stars which are far away from us.

Stars Vary in Brightness. You need only look at the heavens on a clear night to see that there are considerable differences in the brightness of the stars. If you examine them very carefully you will see, even with the naked eye, that there are differences in colour as well, though these are not so easily detected as the differences in brightness. The question arises, Why the differences in brightness? Are they due to the fact that some stars are much larger than others? Are they caused by differences in surface brightness, apart from size? You have often looked at two electric bulbs of the same size, and noticed a considerable difference in their luminosity. Then again, is it possible that the differences in luminosity arise from the various distances of the stars? The answer is that all three factors are at work, and one very important task which the astronomer has to undertake is to find out how much is due to each cause separately.

A detailed explanation of this fascinating branch of

astronomy would be quite impossible in a small wor like the present one, and readers must accept the resul which are given. Later, when they have mastered th elementary principles set forth in this volume, they ma feel disposed to pursue the subject in more advance works which will supply full explanations of the astron mer's equipment and of the results which he is able t obtain from its use. Here is one example of the sensitiv instruments employed. It is necessary to find how muc heat a star radiates to know something about its physic conditions, and very delicate instruments have bee invented to do so. The heating effect of a star fa beyond the range of naked-eye observation—in fac visible only in a good-sized telescope—is about the sam as the heat that we should derive from a candle 2,00 miles distant. Yet this heat can be measured by "thermocouple" used in conjunction with a larg telescope!

Magnitudes of Stars. It is convenient to have som standard of brightness when we are referring to differer stars, and the method in universal use is as follows:—

A star of magnitude 1 differs in brightness from a sta of magnitude 2 in such a way that the brightness of th first is 2·512 that of the second. *It is important t remember that the smaller the number denoting a star magnitude, the brighter is the star.* Similarly, a star c magnitude 2 is brighter than one of magnitude 3 in th same ratio, so if we could imagine 2·512 stars of magn tude 3, the combined brightness would be the same a that of a star of magnitude 2, and so on. When w compare stars of different magnitudes which are nc consecutive, say a star of magnitude 1 with a star c magnitude 3, we take the difference between 3 and (which is 2) and raise 2·512 to the second power—that i square 2·512. The result, 6·31, tells us that a star c first magnitude is 6·31 times as bright as a star of magn tude 3. The same would apply in other cases—that is, star of magnitude 4 would be 6·31 times as bright as star of magnitude 6, and so on. Now suppose we wan to know how many times brighter a star of magnitude is than a star of magnitude 6. Subtract 1 from 6 an

the result is 5; multiply 2·512 by itself four times (usually expressed in the form $2{\cdot}512^5$), and it will be found that the first-magnitude star is just 100 times as bright as the star of sixth magnitude. This shows that there is a certain amount of simplicity in the scheme, because it is easy to remember that a first-magnitude star, of which there are twenty (and fourteen of these are visible in our island), is exactly 100 times as bright as the sixth-magnitude star, which is just visible to the naked eye.

Sirius, Rigel, Capella, Vega, Betelgeuse, Aldebaran, Spica, Pollux, and Regulus are some of the best known first-magnitude stars, and you should learn their positions with the aid of a star map. Brighter stars should be known first, and then later on the fainter stars can be learnt by noticing their positions with reference to the conspicuous stars.

Sizes and Densities of Stars. Dealing with the first factor referred to as making some stars look brighter than others—the fact that some stars are very much larger than others—many results which have been obtained in comparatively recent times are interesting. It has been found that there is an enormous difference in the sizes of the stars, but, strange to say, our sun, which is just a star like the others, is a fair average in size as well as in mass and temperature. We have already shown that the sun's diameter is 864,000 miles, and this will be a useful unit for comparing the diameters of some of the other stars. The mass and density of the sun will also be taken as units, and those of the other stars will be expressed in terms of the sun. Thus, if the density of a star is given as 0·0021, it means that this is its density if the density of the sun is 1. Suppose we want to find the star's density in terms of the density of water. We know that the sun's density is 1·41 times that of water, and hence the density of the star would be 0·00296 that of water. The same method applies to the mass. If this is given as 4, it means that the mass is four times that of the sun, and as this is 2×10^{27} tons, the mass of the star would be 8×10^{27} tons.

One very remarkable thing is that, although the sizes and densities of stars vary very much, yet the differences

in their masses are not very great. Not many stars have been discovered with a mass more than ten times or less than one-fifth that of the sun, but there are exceptions to this.

Name of Star	Diameter	Density	Mass
Antares	480	0·00000021	30
Aldebaran	60	0·000014	4
Arcturus	30	0·00021	8
Capella A	12	0·0014	4·2
Sirius B	0·034	19,000	0·96
o_2 Eridani B	0·019	45,000	0·44

Some of these figures present interesting features. Let us examine those of Antares at the beginning of the list. Perhaps the first thought which will occur to readers is that, as it is so large it must be intensely hot, but this is not correct; in fact its surface temperature is about half that of the sun. Its small density is the most remarkable thing about it. It is difficult to form any conception of this low density—about one three-millionth of the density of water. Water weighs 773 times as much as air at sea-level, so that the density of the star must be about one five-thousandth part of the density of air. In contrast with this very low density, its diameter is enormous—about 415 million miles. We have seen that the greatest distance of Mars from the sun is 141 million miles, hence it would be possible to place our sun and Mars in his present orbit inside Antares, the sun being at the centre, and there would be more than 60 million miles to spare before reaching the outside of the star. It may be remarked that Antares is about 380 light-years from us, and it ranks amongst the first twenty brightest stars in the heavens.

The second star, Aldebaran, is a little brighter than Antares, but is only one-sixth of the distance of Antares. We should expect that it ought to be much brighter because it is so much nearer to the earth, but this is one illustration of the fact that the brightness of a star does not always depend on its distance from us. While the rule that brightness falls off with distance holds in

eneral, yet there are many exceptions, because, as we ave seen, size and surface brightness are also important ctors in determining the brightness of a star.

White Dwarf Stars. At the end of the list are two ars which have densities beyond anything that we ever xperience on this earth. Sirius B has a density 19,000 mes that of the sun, or about 27,000 times that of water -a remarkable contrast with Antares, which is like a as bubble. Although the diameter of Sirius B is only ne-thirtieth that of the sun, and hence the volume is ne-twenty-seven-thousandth that of the sun, the mass is early the same. It is easy to show that with such a ensity a cubic foot of the material would weigh 750 tons cubic foot of water weighs 63 pounds), and it would be mpossible for a man to lift even a cubic inch of the aterial of this star. The figures refer to the *mean* ensity; actually the density increases as the centre of the ar is approached. Sirius B is known as a "white warf," the first word denoting its colour and the second s size. Its high density arises from the crushed state of atter which composes it, and it is believed by some at this will be the fate of the stars in general, including e sun. A discussion of this would lead us too far in an ementary treatise, and we must now look at some other culiarities of the stars.

It may have occurred to the reader that the enormous ars and the small stars which have just been referred to erely represent different stages in the evolution of stars. his conjecture is correct.

Stellar Evolution. In the table on the previous page e star Capella A is included in the list. This star has a ameter 12 times that of the sun, and its surface tempera- re is about 1,000° C. less than that of the sun. It is own as a red giant, and a characteristic of this class is at it possesses a large diameter and low surface mperature, as well as a small density. The temperature the interior of these red giants, as with all stars, is eater than on the surface, but it does not attain the lue of the temperature in the interior of our sun or other nilar stars. Thus it has been estimated that the mperature at the centre of Capella A is only 5 million

degrees Centigrade, which is about one-fourth t temperature in the central regions of the sun. It believed that each star begins its life as a giant globe gas which is very rarefied and cold, but its own gravitati causes it to contract and to increase in temperatu When the contraction has proceeded for some time t central temperature may rise to a million degrees, a owing to the heat energy released in the interior t contraction is stopped. After a certain period, howev the output of energy has diminished to such an exte that contraction begins again, and then, when a high temperature has been attained, it ceases once mo The process is continued until the temperature of t star is high and its luminosity is considerable. Duri this process the star is continually transforming its ma into radiation of heat and light,* so that the older a st is, the greater the amount of matter it has transform in this way. It has been estimated that the sun is losi his mass at a rate of 4,000,000 tons every second, a though this seems an enormous amount, it is extreme minute when compared with the mass of the sun. Sta with different masses run through their evolutiona lives at different speeds ; the heavier a star is, the soon it will reach maturity, old age, and final death, so far emission of heat and light is concerned. After attaini a high luminosity, due to increasing temperature throu contraction, at which stage the star is a giant, the fin contraction begins and eventually leads to the death the star.

The white dwarfs, of which Sirius B and Eridani B a typical, present certain difficulties. Not many of the remarkable stars are known, but this does not necessari imply that they are actually scarce. Owing to the fa that they emit a very feeble light, it is difficult to dete

* When we burn a piece of coal the weight of its ashes and t smoke emitted is very nearly the same as the original weight of t coal, but not quite. To make up the original weight it is necessa to add in the weight of the light and heat emitted during cor bustion. This analogy explains the meaning of the transformatic of some of the sun's mass into radiation of heat and light. T weight of the oxygen which enters into chemical combination ignored, to avoid complicating the analogy.

them unless they are fairly near us. Within recent years Luyten and Kuiper have made a special study of these bodies and their list now includes about forty white dwarfs. It may be presumed that there are others at greater distances which will escape discovery for many years and perhaps a large number will never be discovered.

Sir James Jeans has informed us that the sun is perilously near the stage where it might collapse into a white dwarf and the diminution of its light and heat would imply the end of all life on the earth. Nevertheless, although a reduction of only three per cent in the sun's luminosity would place our luminary on the edge of the precipice where it would collapse, we are assured that this cannot happen for at least 150,000 million years. In addition, the sun is not heading straight for the precipice, but is skirting it, so on the whole we have a respite for another million million years. Professor G. Gamow, George Washington University, presents us with a similar picture of our future, but before the sun collapses into a white dwarf he thinks there will be an enormous increase in the amount of solar radiation, which will make life very difficult if not impossible on our planet. However, the slow rise in temperature will probably be accompanied by evolutionary changes in the biological world, and some terrestrial life will be able to adapt itself to the increasing heat. He does not believe that the higher species will be able to accommodate themselves to the increased temperature, so that the last radiation efforts of the sun, after its output of heat is succeeded by the collapse into the white dwarf stage, will be observed only by the simplest of micro-organisms.

The prospect is not very enticing, but the present writer's opinion is that millions of years before there is any noticeable alteration in the amount of the solar radiation, *Homo sapiens* will have become extinct like hundreds of other species which once flourished on this planet. From the point of view of a member of the human family perhaps he should express some regret at the fate of the species to which he belongs, but from the cosmic point of view there is little or nothing to deplore in this final issue.

Questions

1. If you were uncertain whether an object was a planet or a sta how would you decide by naked-eye observations?
2. Why is it impossible to determine the distances of the sta in the same way as the distance of the moon is found?
3. Why do stars differ in brightness?
4. In what respects do some stars differ very much from th sun, and in what special way is there an average relationship betwee the sun and other stars?
5. Describe briefly the course of stellar evolution.
6. What is the difference between a red giant and a white dwarf
7. What, according to the most recent research, will be th ultimate fate of the sun?
8. What possible alternatives await (*a*) human life, (*b*) all form of life on the earth?
9. Why is the title " fixed star " applied to the stars when nor of them is at rest? In what respect can you consider them to b fixed?
10. Close to Castor, magnitude 2, is the star ρ Geminorum magnitude 5. How many times is Castor brighter than ρ Gem norum?

CHAPTER VII

THE STARS (*continued*)

Double Stars. To the naked eye every star is a single
oint of light, but even a small telescope will show that
any of them have one or more companions close to
em. It must not be inferred that these other stars
hich appear in a telescope to be close to the brighter
ie are necessarily connected with it. They may just
ppen to lie nearly in the same line of sight, but one may
scores of light-years farther off than the other. In
ch circumstances the members or components are
lled " optical doubles." Interesting as they may be,
ey are of little or no scientific importance. There is,
wever, another class of double stars which presents the
tronomer with some of the most interesting and
luable problems in celestial mechanics. Not only do
ese stars seem near to one another; they are actually
rly close and they are revolving round their common
ntre of gravity just as the earth and moon do.
These double stars are known as " binaries," and their
riod of revolution varies from a few days, when they
very close together, to hundreds of years when they
widely separated. Not only are there binaries which
volve round the common centre of gravity; triplets and
adruplets and even greater numbers have been found
ich do the same thing, and these present a problem
ich the mathematician has never been able to solve.
is not a very difficult thing to explain the revolution
two bodies around their common centre of gravity
d to predict exactly where each one will be at a certain
ie. It is impossible, however, to do the same in the
e of three bodies, unless one of them has a very small
ss, and of course it is equally impossible to tackle the
oblem when there are four or more. Here is a case
ere phenomena in the universe baffle the mathemati-
n and probably will continue to baffle him.
n the previous chapter reference was made to Sirius

B, the companion to Sirius. Many years before th companion was discovered it was known that it was the because Sirius was observed to move in a wavy cou —a clear hint that it was revolving round some cent Twenty-eight years later the companion which had be suspected was found by Alvan G. Clark, a telescop maker, who was testing a new refractor.

Many double stars present a beautiful appearan even with a small telescope, and their beauty is som times enhanced by the diversity in the colour of the co ponents. If you have the opportunity to look at ε Ly you will see that it is a quadruple system. Sometin there are six components, like θ Orionis in the swo of the well-known constellation of Orion. If a planeta system existed in connection with a binary or a syste of three or more stars, the movements of the plan would be very complicated and it would require supe minds to predict where a planet would be at any time.

When the time of a revolution is known fro observing the motions of the components over a su ciently long period, and we also know the distance of t system from the sun, it is possible to measure t combined masses of the stars. In this way many sta have been weighed. Their masses have been found differ widely, though there are decided limits. O system has been found in which the masses of t components are at least 75 and 63 times the sun's ma but this is very exceptional, and it is almost certain th few such systems exist. On the other hand, there is lower limit to the mass of a star. The faintest memb of the triple system o_2 Eridani has a mass only one-fif that of the sun, and this is the smallest mass in any st yet discovered.

Research on binaries is a specialized branch astronomy, and there are many very important probler arising out of it, some of which are concerned with th ages and origin of the stars. It would be impossible deal with these at present, and we shall now proceed consider another kind of star which also preser fascinating problems, some of which still await solutio

Variable Stars. Eclipsing Binaries. Those who ha

not made a study of elementary astronomy are under the impression that each star always emits the same amount of light, and that variations in the brightness of a star are due to atmospheric conditions. This is not correct, however, and there are a great many stars whose magnitude change, some in a regular manner, others in ways that seem erratic. There is one star in particular which can be observed to change rapidly in brightness in the course of about 3 hours. The sudden fluctuations in the light of this star were known to the Arabians, who called it Algol, meaning the " Demon Star." It is still known by the name Algol, but a more scientific designation is β Persei. Its phases are briefly as follows: In about 2½ hours it descends by two magnitudes in brightness and remains for 20 minutes like this ; then it begins to brighten until it regains its original condition after another period of 3½ hours. For 2½ days it remains bright, and then the changes begin again and run through the same phases in a most regular manner.

The previous section dealt with binary systems, and the reader may now conjecture the reasons for the variations in the light of β Persei. Suppose that one of the components is not so bright as the other or that it is almost a dark body, and also that the plane of the orbit in which the stars revolve is edgewise or nearly so to us (see Fig. 10). In these circumstances some of the light of the brighter body will be cut off when the other component comes between its companion and the earth. This is what happens in the case of β Persei and other "eclipsing binaries"—the name given to this class of variables. If the plane of the stars' orbit is not edgewise to us there will be less shutting off of the light than in the case where it is absolutely edgewise, hence eclipsing binaries will not always show the same amount of change in brightness. There are other reasons why the changes would not be the same for different systems—among which the relative size and brightness of each component are important. Five more of these eclipsing binaries can be observed with the naked eye, and probably the most convenient of these for studying is β Lyrae. The interval between its times of minimum brightness is

nearly 12 days 22 hours. Many eclipsing binaries ex whose changes in brightness can be detected only with t delicate instruments at the disposal of the astronomer.

Long-Period and Irregular Variables. There a several other classes of variable stars, and we shall d with the long-period variables and the irregular variab —names which suggest the characteristics of these class

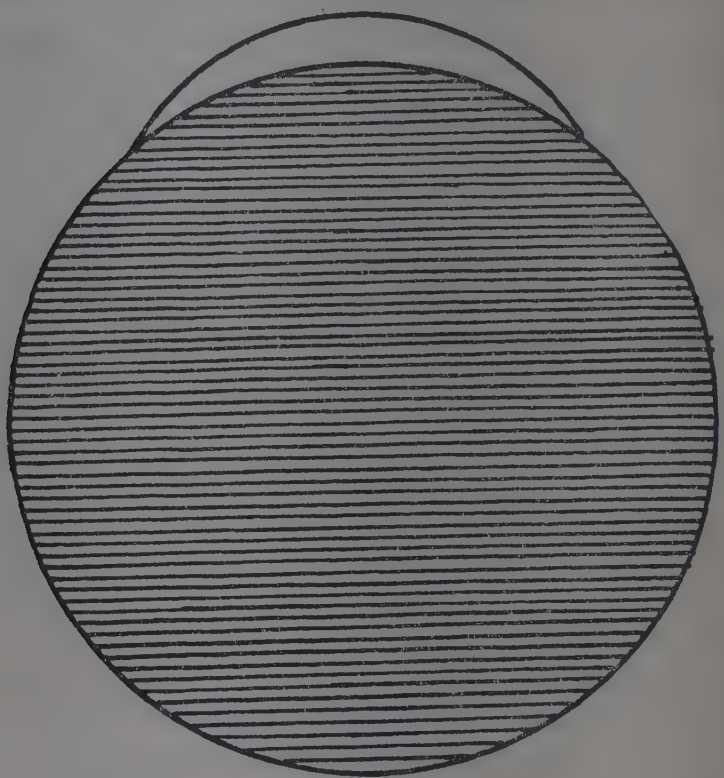


FIG. 10.—Showing an eclipsing variable. Hold the paper bef the eye which can be taken as the position of the earth. brighter star has almost completely passed behind the dar one and hence there is a marked falling off in its light.

The long-period variables are red giants, of which sor thing was said in the previous chapter, and their perio range from about 2 months to 2 years. The m common period is in the neighbourhood of 300 da One well-known example of this class is o Ceti, genera known as Mira, "The Wonderful," which varies fr magnitudes 3·5 to 9 in an average period of 330 da but this time may alter by as much as a month. M

an 1,700 long-period variables have been catalogued, t only about twenty of these are visible to the naked eye. Irregular variables are also red giants, but they differ om the long-period variables in certain respects. First all, it is absolutely impossible to predict what they will . In the next place, they do not alter to the same tent as the long-period variables, their variations dom exceeding half a magnitude, and very often they e much less than this. A well-known star of this class Betelgeuse in Orion.

The Cause of Long-Period and Irregular Variables. e astronomer is not content merely to record what he serves; he seeks for an explanation of the phenomena, d so he has tried, not with complete success, to plain the cause of the long-period and irregular riables. A theory to explain these and also the Cepheid riables (see next paragraph) is as follows.

A large gaseous star contracts under its own gravita- n, and in doing so becomes hotter. A familiar mple of this kind of heating is found in a pump for a or bicycle. Compressing the air inside the pump ses the air and the pump to grow warmer, as anyone verify for himself. Again, when a gas is heated it ds to expand. If anyone doubts this he can hold a ld's toy balloon or a blown-out football bladder close a fire; the pressure from the heated gas which is trying expand will quickly burst the balloon or bladder. In same way the heated gas in the contracted star will oduce an expansion, and this in turn will cause a tain amount of cooling. When cooling has gone to a tain stage, contraction will commence again, and the ocess will be repeated. This action has been likened the beating of the heart. During the expansion and ntracting of these stars it is thought that the diameters y change by as much as 10 or even 15 per cent, while range of temperature may be 1,000° C. In the ansion stage the star becomes brighter, and as it ntracts, although it is hotter, it becomes smaller, and ce gives less light. While this "pulsation theory" open to certain objections, it provides a tentative lanation of the varying brightness of these stars.

Cepheid Variables. This class of variables takes name from δ Cephei, one of the earliest recogniz examples. Their periods vary between a few hours a about 50 days, and, with a few exceptions, their lig variations are continuous and remarkably regular. T distances of these stars can be determined when th apparent magnitudes and lengths of periods of lig variations are known, but an explanation of the meth is beyond the scope of this work.

Sir James Jeans thinks that the variation in th light arises from rotational instability. His theory that the stars are rotating so rapidly that they are on t point of breaking up, just as a weak fly-wheel mig burst if its rotation were very rapid. Some stars a rotating rapidly, and so their equatorial regions bu to an enormous extent. In an earlier chapter we s that Jupiter's equatorial diameter exceeded his po diameter by more than 6 per cent, but in the case of t variables under consideration the equatorial diame may be twice as long as the polar diameter. Altern expansion and contraction of this long axis in combinati with the rotation explains some of the phenomena these variables, but other peculiarities are not explair satisfactorily in this way, and much still remains to done to account for the light changes in this type of sta

Novae. In addition to the variables which have b considered, there is another type of star which might described as a variable, but which differs so much fr the other stars of this class that it has a special title of own—Nova or Temporary Star. These stars rise v suddenly from obscurity to a great brightness and t sink back again into faint stars. Five brilliant no and also a number of dim novae have been discove in the present century. The last bright one was discove early in 1934 by Mr. J. P. M. Prentice, Director of Meteor Section of the British Astronomical Associati who was looking out for meteors at the time.* T

* Just before the MS. was sent to the printers, information received that a nova was discovered by Mr. T. Ellis, Llandu North Wales, on the morning of November 13, 1942. Its magnit at the time was about 2 and it was in the Constellation Puppis.

nova, which is known as Nova Herculis, from the name of the constellation in which it was discovered, flared up to brighter than 2nd magnitude. Photographs which had been previously taken of this region of the heavens showed that there was a star where the nova appeared and that its magnitude was 15. A calculation which can be made from the data supplied in the previous chapter shows that this star must have increased its luminosity 160,000-fold in the course of a few days.* The sudden change indicates that the surface of the star must have got enormously hotter in a very short period, and suggests that there must have been something like an explosion. In some cases the speed of the gases surrounding a nova has been shown to exceed 1,000 miles a second, and observations show that successive surface layers are blown off at intervals of a few days.

An interesting fact in connection with Nova Persei, discovered in 1901, is worth mentioning. A few months after its outburst a faint glow was photographed around the star, and this was seen to increase at a rate which was later found to be the speed of light. This did not imply that the material blown out of the star was receding with this speed. It showed that the star was within a region containing dark cloudy matter which was illuminated by the sudden light produced in the nova. This light spread outwards from the star with a speed of 186,000 miles a second and illuminated the previously dark nebula, which then seemed to an observer on our planet to be expanding with the velocity of light.

Cause of Novae. The precise cause of a nova is not known, but we are fairly certain that the possible causes can be narrowed down to a very few. A collision with another body has been suggested, but the chance of this is too small to account for all novae, including those which we can see directly and more which the camera detects. A more likely theory is that the star collides with a cloud of nebulous matter, producing an enormous amount of heat, just as would happen if a collision between two bodies occurred. We have already seen that meteors are heated to very high temperatures when

* $2{\cdot}5^{12^{18}} = 160{,}000$ approximately.

they collide with our atmosphere, and the same thi would probably occur if a star collided with a nebu Another theory—and the most probable of all—is th the nova is produced by something within the star itse There is a sudden release of energy which is responsit for a high surface temperature and the rapid increase brightness. It is very improbable that anything mc than the surface is affected because the novae genera collapse into faint stars very soon after the sudden fla up, and this would not occur if the greater part of t star had been affected.

Perhaps every star passes through the nova stage some time in its history. If this is so the sun m become a nova, in which case the inhabitants of planetary system on some far-off star, if such planeta systems and inhabitants exist, would announce t discovery of a nova. Needless to say, inhabitants this or any other planet in the solar system would not aware that a nova had appeared, because the wh planetary system would be reduced to the gaseous st in a very short time through the intense heat produc at the time of the outburst.

Questions

1. What is the difference between an optical double and binary?
2. Is it possible by naked-eye observations alone to distingu between an optical double and a binary?
3. What important deductions can be made from a binary syst when the time of revolution and the distance from the earth known?
4. What star can be observed with the naked eye to v considerably in brightness?
5. Explain how an eclipsing binary causes variations in amount of light which reaches us. Use a diagram to illustr your explanation.
6. How do long-period and irregular variables differ fr eclipsing binaries? To what class of star do the former belong
7. Give a short explanation of the two main theories which h been advanced to account for long-period and irregular variat and Cepheid Variables.
8. A nova is a variable star, but differs entirely from the us type of variable. Explain in what respects it differs.
9. What is the cause of a nova? Why do you think tha collision between two bodies is not the cause, generally speakin

CHAPTER VIII

NEBULAE

The Milky Way System or Galaxy. The Milky Way s one of the most impressive sights in the heavens, and probably ancient astronomers were puzzled to explain it. t is remarkable, however, that Democritus, who lived n the fifth century B.C., suggested that it was made up f an enormous number of faint stars which could not e seen individually. It was impossible to confirm or leny this speculation until the invention of the telescope, nd then it was shown that Democritus was correct in is guess. It is not necessary to use a telescope to notice hat the stars in or near the belt are more numerous than hose in other parts of the sky, and in fact all the stars hat we can see with the naked eye belong to the Milky Way system. The term " galaxy " is usually applied to his system; it is derived from a Greek word which neans milk, and is a very appropriate title for this great irdle of the heavens.

The story of the research which astronomers have onducted on the galaxy since the days of Sir William Herschel is an extremely interesting one, but we have no pace to deal with it. All that can be done now is to give he results of many years of patient work on the part of a umber of astronomers who have devoted their time to special study of this portion of the heavens. Owing to he vast distances which separate the extreme portions of he galaxy from one another, it is necessary to express istances in terms of light-years. Later on the dimensions vill be given on the scale of a small model which will ssist in visualizing the immensity of this system of stars n which our own sun is situated.

The galaxy is shaped somewhat like a bun, but is more attened than most buns are. Imagine a bun which is bout six times as long as it is deep, and you will have a ough conception of the shape of the galaxy. Inside his bun-shaped system there are about 3×10^{10} stars—

that is, 30,000 million—which are of various sizes
masses, but which, taken on the average, do not di
very much from one particular star that is important
us—our sun. Light would require about 120,000 y
to cross the galaxy from end to end and about 20,
years to cross its shortest diameter—referred to as
depth of the bun. We might expect that an impor
star like the sun (important at least from our poin
view) would be near the centre of this vast system,
no special preference is shown to it, and in fact i
30,000 light-years from the centre (see Fig. 11). Out
the galaxy there is a vast emptiness, and then we com
more similar galaxies, one of the nearest of which,
Great Nebula in Andromeda,* is nearly a million li
years away from us. This is very close in compari
with some others, which are as far as 140 million li
years away.

On a planet which is part of the system of an ordin
star situated 30,000 light-years from the centre of
galaxy out of 2 million, something which we call life
developed. It has reached its highest intelligent fo
so far as we know, in a species *Homo sapiens*.
species has looked out on the universe and has medita
on the mysteries of its origin and destiny. It has weig
the stars and has analysed the elements composing th
It has plumbed the depths of space and has discov
that its own little planet, and even the whole planet
system of which its own planet is a part, are but a sp
in creation. It has mused on the possibility of
elsewhere in the vast cosmos and has even tried, with
success, to communicate with beings, if such there
on other worlds. At one stage of its history it wa
egotistic that it believed all creation was subservient t
needs and that the myriads of heavenly bodies
specially designed to minister to its wants.

Four hundred years ago, when Copernicus sho

* The nebula M 33 in Triangulum is slightly nearer, its dist
being 850,000 light-years, whereas that of the Great Nebul
Andromeda, M 31, is about 900,000 light-years away.
Magellanic Clouds are very much nearer to us than either of
nebulae, but there is some doubt whether they are outside
galaxy or are part of our galactic system.

hat the earth and planets were moving round the sun, the earth was dethroned rom its central position in the universe, hough man has been very slow to learn he lesson. Until recent times he could t least boast that the galaxy to which the un belonged was unique in dimensions, ut now it seems that there is nothing pecial about it, and even a near neighour in galaxies—the Great Nebula of ndromeda, once believed to be very nuch smaller than our own—is comparble in size with the Milky Way. The rgest telescope in the world, the 100-inch eflector at Mount Wilson Observatory, nows that there are many apparently int nebulae, all galaxies, just at the limit f vision, which is 140 million light-years. here is no reason to suppose that the ebulae end there, and when the 200-inch lescope is completed it will penetrate the epths of space to twice this distance. he most remote nebulae that can be notographed with the 100-inch telescope e about 500 million light-years distant. he 200-inch telescope will probably pene- ate to twice this distance. If the nebulae e distributed as uniformly in those far- f regions as they are nearer to us, then e must expect that 16 million will be scovered.

FIG. 11.—A model of the galaxy. The sun is marked x.

Rotation of the Galaxy. Every galaxy, cluding our own, is rotating, but not like solid disc or a wheel. Different objects d classes of objects in the galaxy have fferent rates of rotation. The sun is oving around the centre of the system hich is in the direction of the dense ar-clouds in the constellation of Sagittarius) with a eed of 170 miles a second, and completes a revolution about 225 million years; of course, he takes with him

the earth and all the other planets and satellites. In
course round the centre of the galaxy the sun m
encounter clouds of cosmic dust, or matter in a ve
tenuous condition, and it is possible that this dust co
exercise some influence on the climatic conditions of
earth, and hence on the various forms of life. It
probable that the dawn of life dates back 1,000 milli
years, in which time the sun made four complete revo
tions round the centre of the galaxy. One co
speculate on the causes of the appearance and d
appearance of many species which once inhabited
earth, but this must be left to the biologist.

A Model of the Galaxy. In order that we may gai
better perspective of the vast dimensions of galac
systems, imagine that our own galaxy is reduced to
model with its greatest diameter * 1,000 miles, which
more than twice the length of England. Our " bu
will then be only 160 miles thick at the centre, and
taper off to about one-fourth of this near the en
Inside this huge bun there are 30,000 million specks w
an average diameter of one ten-thousandth part of
inch, all in rapid motion at various speeds round
centre of the bun. Somewhere about 300 miles from
centre there is a particular speck in which we
interested because it is our sun. Around it a numbe
extremely minute specks are revolving, the outer
named Pluto, at a distance of two-fifths of an inch,
another one, which we call the earth, at a distance
one-hundredth of an inch, from the large speck whic
the sun. On this scale the earth is one-millionth o
inch in diameter, and so would be invisible even i
powerful microscope. About 80 yards away from
planetary system (it makes no difference whether
measure from the sun, the earth or Pluto) there is a sta
Proxima Centauri—which is the next large speck to
sun. The most distant speck which is inside the bu

* Estimates of the size of the galaxy and of the number of
which it contains vary very much. The model is based
diameter of 100,000 light-years, which is probably less tha
actual diameter. The number of stars has been estimated t
anything between 30,000 and 100,000 million.

about 800 miles away, and then, when we go outside it, there is a vast void for 9,000 miles before we come to the next bun, which is M 33 in Triangulum. This is our nearest galactic neighbour, and it is comparatively close, since some have been detected with powerful telescopes more than 1½ million miles away on this scale. Bear in mind that the earth is one-millionth of an inch in diameter according to the model of the galaxy. We see the most distant galaxy by the light which it emitted 140 million years ago. Many of the stars of this far-off system may have exploded and become novae for a few months, only to collapse again into faint stars. Perhaps a few may have collided and have ceased to exist as stars any longer, being turned into huge volumes of gas, while planetary systems with their inhabitants have perished like a moth in the furnace. Our telescopes are not sufficiently powerful to notice such trivial matters as these, and if they could reveal these cosmic upheavals it would be 140 million years after they occurred—probably three or four hundred times the period during which human life has existed on the earth. Such are the distances and the time scale which are used in dealing with cosmic problems.

The Spiral Nebulae or Extra Galactic Systems. The galactic systems far beyond the outlying stars of our own galaxy are called spiral nebulae, although many of them show no signs of the spiral form. If the plane of a flattened system is perpendicular to our line of sight it is easier to detect the spiral form than if it is edgewise to us. In the case of the Andromeda nebula the plane is inclined at an angle of 15° to the line of sight, and this is sufficient to reveal its structure. Towards the centre of the spiral the substance of the nebula is denser than the arms of the spiral. Owing to this feature the nuclear region of the Andromeda nebula can be seen with the naked eye, and no other spiral nebula can be seen without telescopic aid. Some nebulae are turned with their planes practically at right angles to the line of sight and exhibit the spiral form, including two great spiral arms very clearly, as in the case of M 51 in Canes Venatici. If our Milky Way could be viewed from a suitable position

outside our system it would probably present the appea ance of a spiral nebula, like other galaxies. We ha seen that our galaxy is in rotation, and the same appli to the spiral nebulae. Measurements of the rate rotation of M 31 suggest that 19 million years a required for a complete rotation, and this implies that t outer portions must be moving at hundreds of miles second. It is fairly certain that a galactic system mu have been produced out of a rotating body, or, rather, gaseous mass.

The Spiral Nebulae are Running Away from Or Another. A remarkable fact has been brought to lig in recent times regarding the motions of the spir nebulae. They are all running away from us and fro one another, but not at the same speed, since the mo distant ones are moving faster than those nearer to u It has been found that a nebula at a distance of 3½ millio light-years has a speed of about 330 miles a second, an if the distance is doubled, the speed is doubled too; the distance is halved, so is the speed. This extra ordinary flight of the spiral nebulae involves some ve difficult problems on which astronomers are not y agreed, and the reader must be content to accept the fa that the nebulae are running away from us and from or another, without inquiring into the reasons for this strang behaviour.

Nebulae Which are Part of our Galactic System. It rather unfortunate that the name "nebulae" shou have been applied to the enormous stellar systems fa beyond the Milky Way, as well as to a class of objects our own galaxy which are utterly unlike stellar system In appearance they are similar; both are like a wisp mist or cloud (the word "nebula" is the Latin for cloud, mist or fog), but there the likeness ceases. Tw types of nebulosity are found in the galactic syste There are the *diffuse nebulae*, of which the Great Nebu in Orion is an example; the luminosity of these is n due directly to a multitude of stars, as in the case of t spiral nebulae, but indirectly to the influence of a fe stars lighting up dark matter in space. When you loo at the Milky Way you will notice that it is not all equa

studded with stars; in some parts there are clouds between us and the stars beyond, and this obscuring matter cuts off the light which would otherwise reach us. The luminosity of diffuse nebulae is due mainly to the light from associated stars; the light of the stars is reflected by the fine dust, or perhaps very rarefied gas, which otherwise would be merely dark matter. In addition to the reflection of the light of stars, it is certain that the very hot stars are able to excite some of the gases in a nebula to glow, and so we see diffuse nebulae not so much by reflected light, as by light which they emit under the stimulus of very hot stars. The Great Nebula in Orion, in which the star θ Orionis is situated, is about 600 light-years from us—quite a short distance in comparison with the nearest spiral nebula.

Planetary nebulae present a different appearance from the diffuse nebulae. As their name suggests, they are like a planet, inasmuch as they are round, or nearly so, and they are smaller than the diffuse nebulae. One of the most beautiful of all the planetary nebulae (of which seventy-eight can be seen in the northern sky) is the Ring Nebula in Lyra. As we might infer from its name, it resembles a ring in its luminous portion. The central regions are dark owing to obscuring matter. The diameters of about twenty planetary nebulae have been found, and they are several thousand times that of the solar system. In most cases they have a white-hot star at their centre, and this star is responsible for imparting light to the whole nebula. It is certain, however, that it does not shine by reflected light as the moon does, because the nebula is brighter than it could be if reflected light alone were responsible. In some way the light of the very hot star is able to start the gases shining, as happens with the diffuse nebulae, but the actual process still remains in doubt.

How the Constitution of Celestial Bodies is Known. Up to the present nothing has been said about the method which is used to distinguish between the different kinds of nebulae, especially between those which are outside our system and those which are part of our galaxy. The instrument which the astronomer employs for finding the

chemical composition of the stars and nebulae is know as a spectroscope, and it is simply an apparatus f studying a spectrum. When ordinary sunlight is pass through a prism it is broken up into its constituent par consisting of all the colours of the rainbow—viol indigo, blue, green, yellow, orange, red—and the str of coloured light which the prism throws on a sheet known as the spectrum of sunlight. Beyond both t red and the violet ends of the visible spectrum there a rays which we cannot see. These are the infra-r (below the red) and the ultra-violet (beyond the viol rays, the latter being particularly effective in photograph work.

Sunlight is not, of course, the only thing that produc a spectrum, or at least a portion of one. When a substance is made white-hot and its light is examined by spectroscope (which is simply a combined prism a telescope, with a lens to make parallel rays from t white-hot substance fall on the prism), the spectroscopi by examining the spectrum, possesses a lot of useful da Every element has its own peculiar spectrum of brig and dark lines, and the spectroscopist knows exact what each line means, so he has a mine of informati at his disposal when he studies the spectra of stars a nebulae. He knows whether the light which comes fro those bodies, separated from him by millions of lig years, is produced by a star or a glowing gas, and he c tell us a lot about the elements which go to make up t star. These elements, it may be remarked, are simil to the elements which he finds in the sun, and these aga are similar to those found on the earth.

Another very important thing the spectroscope can is to tell us the speed with which a body—star or nebu —is approaching the earth or receding from it. This done by noticing how far certain lines in the spectrum a displaced from their usual position in which they a found when the object under examination is at rest. W have already referred to the gases methane and ammon which largely compose the atmospheres of some of t giant planets. It was by using the spectroscope that the gases were detected. It would be a very long story

tell all that the spectroscope has done, and those who are sufficiently interested in this branch can read more advanced or specialized works, which will explain how so many secrets have been wrested from the universe by this wonderful equipment of the astronomer.

Celestial Photography. The camera is a very useful accessory to the telescope. It is attached in place of the eye-piece of the telescope, and is kept pointed to any particular part of the heavens for any length of time necessary for the exposure. This is done by means of a clock-drive, which causes the telescope to move at the same speed as the earth is rotating, but in the opposite direction. If the telescope were not driven in this way there would be trails of the stars on the plates, but by keeping the camera pointed to the same spot in the heavens, long exposures are possible, and much valuable information is obtained.

There are various advantages which photography has over direct vision. One is that the photographic plate shows stars that are only about one-sixth as bright as the faintest that can be seen by the eye using the same telescope. This is because the eye sees all that it can see in an instant, while the plate may be exposed for a long time—an hour or more—thus intensifying the photographic effect. Again, the camera gives a permanent record, which may be studied at leisure by the astronomer. This is especially useful when it is necessary to count the number of stars in a cluster or when there is a programme for mapping the skies.

Photography is invaluable in the discovery of minor planets. As these objects are moving at an appreciable speed, the telescope which is driven to keep a star image in the same position on the plate will not keep an asteroid image fixed. Hence there will be a trail which the astronomer can study later, and in this way he will recognize a new discovery. Fainter novae are discovered by photography, and often a new comet appears on the plate.

The manufacture of plates sensitive to red light and to light far out beyond red in the spectrum has been responsible for many important discoveries in recent

times. The invention of faster lenses has also produced valuable results. Modern astronomers would be very badly off without their photographic apparatus.

Questions

1. Describe the general appearance of the Milky Way, from your own observations. Why do you notice rifts and dark parts in its structure?
2. What is the shape of the Milky Way? What appearance do you think it would present to astronomers on planetary systems outside the Milky Way?
3. Name the two nearest extra galactic nebulae to our own galaxy. How far away are they?
4. What is the limit of vision of the largest telescope—the 100-inch at Mount Wilson? When the 200-inch reflector, now under construction, is mounted at Palomar Mountain, U.S.A., what will be its limit?
5. How does the rotation of the Milky Way differ from that of a disc?
6. What is the sun likely to encounter in his journey round the centre of our galaxy? Would this have any effect on the climates of the planets?
7. The distance of some far-off spiral nebulae is about 140 million light-years. With what speed would you expect one of them to be moving?
8. Why do we see some extra galactic nebulae as spirals while others have not this appearance?
9. What is the essential difference between the extra galactic or spiral nebulae and those which belong to our own galaxy? Which are the larger?
10. What instrument is employed to tell us about the chemical elements found in the celestial bodies? In what other special way is it used to supply valuable information about the stars and nebulae?
11. Name some of the advantages of photographic over visual methods of observation.

CHAPTER IX

THE ORIGIN OF THE SOLAR SYSTEM

General Orderly Arrangement in the Solar System. It is not a matter of pure chance that all the planets and asteroids describe their orbits in the same direction. The satellites, on the whole, also follow this orderly arrangement, which astronomers call direct orbital motion. There are, however, a few exceptions, which have been referred to in a previous chapter. Among these we may recall the retrograde motion (opposite of direct) of the only satellite possessed by Neptune; the motions of the four satellites of Uranus in the equatorial plane of the planet, which is nearly perpendicular to the plane of the ecliptic, and also the retrograde motion of certain satellites of Jupiter and Saturn. Another important matter which cannot be due to chance is that the planets (but not all the asteroids) move in orbits which are very close to the plane of the ecliptic. All this suggests that there must have been a common cause for the bodies, or at least for most of the bodies, which make up the solar system, and we shall now turn our attention to some of the theories which have been advanced to explain the origin of the planets and satellites.

Laplace's Theory. In 1796 Laplace put forward what is known as the " nebular hypothesis " of the origin of the solar system. He started by assuming a great gaseous mass in rotation, with its matter balanced between the gravitational pull towards its central part and the expansive force of the hot gases. As heat was gradually lost by radiation and dispersed into space, the whole mass would shrink, and hence would rotate more rapidly. This assumption of increasing rotational speed with decreasing size is sound, and actually a rotating and cooling gaseous sphere would spin faster until it bulged out at the equator. Finally, some of the material in the neighbourhood of the equator would be thrown off. We know that if the earth rotated seventeen times as fast as it

does at present, the centrifugal force at the equator woul just balance the attraction of the earth towards the centre and objects would be on the point of being thrown o as the earth rotated.

In the case of the rotating gas Laplace assumed that ring of gaseous matter would be left behind during th shrinking, and the balance would be restored again. Th process would be repeated several times, ring after rin being left behind, and each of these rings would eventuall form a gaseous ball which would finally become a planet During the shrinking of these gaseous balls (whic themselves would also be rotating) smaller rings would b thrown off, and these would condense into the satellites On this theory Pluto was formed first of all from the rin which was thrown off when the sun's atmosphere extende out as far as, or beyond, the orbit of this planet, an Mercury was the last planet which was formed. Afte the ring which was responsible for making Mercury ha been left behind, the sun still went on shrinking to abou its present size, but no more rings were ejected.

This theory explains a number of features of the sola system, but the present writer has always held that th motions of comets alone were a very strong argumen against it. Many people, however, have felt it was s simple, and perhaps so obvious, that it had the appea ance of truth, and for a considerable time it was accepte with certain modifications which were necessary in th light of further research. Unfortunately for the theory it did not satisfy observational evidence, and, in additio it failed very badly under cross-examination by th dynamical astronomer.

Objections to Laplace's Theory. Among the objection we may refer to the rings which were supposed to hav been left behind during the shrinking of the gas. was only a pure assumption that rings would be formed in fact, instead of rings appearing there would be continuous disc of particles which would not form int planets. Even if a gaseous ring were left behind, would scatter into space because its own gravitation pull would be too weak to hold it together in the cond tions prevailing at the time when the rings were suppose

to have been formed. Again, it has been shown that the sun could never have had sufficient rotational velocity to cause the breaking off of matter in equatorial regions. The theory gives no explanation of both direct and retrograde orbital motion of so many comets; nor does it account for a similar phenomenon which has been observed in the case of several satellites, supposed to have been formed from rings shed by the gaseous ball which formed the planet. Another difficulty is the inner satellite of Mars, which, as we saw in an earlier chapter, revolves in a shorter time than the planet rotates. This could not be so if the satellite had been formed from a ring left behind by Mars when it was in a more or less gaseous condition.

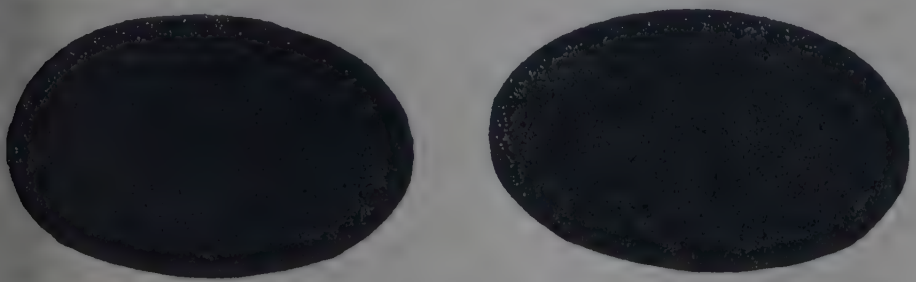


FIG. 12.—Showing the tidal effects when two stars approach each other. The stars are drawn out in egg-shaped fashion. Finally, if they come sufficiently close, disruption occurs.

These and other objections have been urged against he theory, and it is no longer accepted as an explanation of the origin of the planets, satellites, and comets.

The Planetesimal Theory of Chamberlin and Moulton. An interesting theory to explain the origin of the planets was developed in 1900 by Chamberlin and Moulton, the former a geologist and the latter an astronomer, both Americans. According to this theory a star passed near he sun some thousands of millions of years ago and produced great tides in it (see Fig. 12). At that time he sun was subject to eruptive forces such as prevail now, but on a more violent scale, and these were ntensified by the tidal strains. The result was that natter was thrown off the surface of the sun, and omething like a small spiral nebula was formed. This dea is worked out in detail by the authors, and it is

possible that a visiting star would produce the effe described provided it came sufficiently close. It assumed that the star came well within the limits of t present planetary system, and though its tidal effe would in themselves be too small to produce disrupt unless the centres of the two bodies were only a f millions of miles apart, nevertheless, when these effe were combined with the sun's eruptive forces, someth like great ejections of gaseous matter might occur.

When the visiting star had receded, the eject materials were left revolving around the sun in differe orbits, and cooling took place, so that small solid bod were formed. Larger nuclei then swept up these smal bodies, and as a result the giant planets were evolv the asteroids arising from masses of material witho any very large nuclei. The satellites grew up arou secondary nuclei, which may have been associated wi their planets from the time when ejection occurred, they may have been captured by the planets when th became entangled in the outlying parts of the planeta nuclei.

Professor Bickerton's Theory of Grazing Collisio Before the planetesimal theory was advanced a theory " grazing collision " was formulated by A. W. Bickert in New Zealand. Bickerton was a physicist and chemi but his attention was drawn to astronomy by t appearance of a nova, which he explained by assumi that two bodies had collided, not directly, but with slanting blow. He applied his " grazing collision theory to explain many celestial phenomena, and show how such a collision between a star and the sun cou produce the planetary system. His views were publish in a New Zealand Journal which was not devot primarily to astronomy, but later they were embodi in a work with the title, *The Birth of Worlds and Systen* published in 1911, thirty-three years after he had fir propounded his views. He had left New Zealand an had settled down in England shortly before the public tion of the work just mentioned, and though his theo was then many years old, it is doubtful if it was known more than a few British astronomers. Bickerton

enthusiasm in attempting to propagate his tenets regarding novae, the origin of the solar system, and other celestial problems, was never damped by the cold reception which they met in this country. Unfortunately his method of handling some problems in dynamical astronomy left much to be desired, and he gained very few adherents to his theory. It should be added that since his death there are some eminent mathematical astronomers who have not only regarded his theory as feasible, but have also admitted the necessity for a grazing collision to explain the origin of the planets. Although his views were not generally known in this country until thirty years ago, he first formulated them in 1878 and so he antedated the planetesimal hypothesis by many years.

Sir James Jeans's Tidal Theory. Sir James Jeans turned his attention to the problem in 1916 and showed that there was no necessity to assume eruptions on the sun as Chamberlin and Moulton had done. Tidal action produced by the passing star would, he believed, be sufficient to explain disruption of the surface of the sun. He thought that the primitive sun which was disrupted extended to the distances of the outermost planet, but later on he accepted the view of Dr. H. Jeffreys that the sun at the time was something like its present size. If there were a strong central condensation, the approach of another star would not produce disruption into two nearly equal portions like a binary star, but would draw long filaments out of the sun on two sides. The condensation of the filament would ultimately produce the planets, and when these in turn passed near the sun the process would be repeated on a smaller scale, portions of the primitive planets being removed, and these would form the satellites.

Rejection of the Tidal Theory. Although Jeans thought that the visiting star made a very close approach to the sun, he considered it was unnecessary to assume a collision. Dr. Jeffreys showed that certain features in the solar system were inconsistent with the views of Jeans, and he argued that a grazing collision, similar to that which Bickerton suggested, must have taken place. While this assumption rendered it easier to explain some

things about the planetary system, other more serio difficulties arose, and the Tidal Theory of Sir Jam Jeans is no longer accepted as an explanation of t origin of the solar system. The same remark appli to the planetesimal theory. Many other objections ha been raised, but it is beyond the range of this elementa treatise to deal with all the objections to both theorie and the reader must accept the statement that they do n explain the origin of the solar system.

Recent Theories. Since the rejection of the Tid Theory other attempts have been made to explain t planetary system, and these rely on some form of di ruption, but with various modifications which, it wa believed, would not meet with the usual objectior Dr. R. A. Lyttleton advanced a theory a few years ag which assumed that the sun was a binary star and that i companion was disrupted by the visiting star, the plane and satellites being formed from the debris. This theo was published in the *Monthly Notices of the Roy Astronomical Society* (96, 6, 1936 April), and criticis at different times led to a considerable amount modification in the original views. Indeed, the theo was modified so much that at the end some portions of bore very little resemblance to the original, and it ha not received general acceptance in astronomical circle It became very complicated and involved a large numb of highly speculative assumptions—not always conduci to a favourable reception. Like some other theorie that of Lyttleton found a difficulty in explaining the orig of the satellites, though other equally formidab problems remained for which no adequate explanatic could be found. Lyttleton expressed the views cosmogonists when he said that nothing approachi exactness can be attained in discussing certain featur of the problem.

Another theory was recently published, and in fact under discussion while this chapter is in course preparation. In *The Journal of the British Astronomic Association* (**52**, 6, 1942 July), Mr. J. Miller advanced theory of the formation of the planets in which a stell cluster plays a prominent part. The stellar cluster ac

like the " visiting star " in some of the earlier theories, except that the sun approaches the cluster, and so is itself the intruder, suffering for this intrusion, in its revolution round some centre of force, by being disrupted. Cohesion of the particles in the sun is an important factor, as it assists the sun's gravitational attraction on the outer layers in preventing disruption until a sufficiently close approach has been made to the cluster. Assuming that cohesion is very small on certain outer layers, these would be the first to be removed when the sun and cluster were a considerable distance apart, and the outermost planet Pluto was formed from the debris. Closer approaches of the sun to the cluster were followed by the ejection of more material as the attraction of the cluster increased through the nearness of the sun and overcame the gravitational pull of the sun on its outer layers and the cohesion of the matter forming these layers. From this ejected material Neptune was formed, and the process was repeated until Mercury was produced from matter ejected at the nearest approach to the central attracting force—the stellar cluster. No attempt is made to explain the origin of the satellites, but it was suggested that a future paper would attack this problem.*

Summary of the Position. The position at the moment is that there is no generally accepted theory of the origin of the planetary system—including, of course, the satellites, comets, and meteors. A tentative view is that somewhere about 3,000 million years ago, or probably longer, matter was ejected from the sun by some means, perhaps by a combination of circumstances which may not often happen in stellar systems. This matter condensed through its own gravitational attraction into planets of various sizes and densities, Mercury being the least and Jupiter the greatest. Then, when these planets made close approaches to the sun before their orbits became nearly circular, the satellites were torn out of them in turn. In a molten planet the heavier

* At the time of reading the proofs, another theory by Mr. B. M. Peek has appeared in *The Journal of the British Astronomical Association* (53, 1, 1942 December). It is a modification of the theory of Laplace.

materials would settle down towards the central regi and this is what we find in the case of the earth, explained in Chapter I. In the course of some thousa of years gases would become liquids, and liquids wo become solids, but it is difficult to say how long would require. After the formation of the crust w cooling had gone far enough and the ocean had c densed, conditions must have become favourable for development of life.

The process of development and also the necess conditions still remain a problem, though much has b done in recent years to suggest certain factors that w probably at work. It is possible that life appeared m than 1,000 million years ago, but as it would have b in the form of tiny specks of protoplasm, it could le no fossil remains. For this reason it is quite impos to say definitely when life originated, and the few fo found in the Archaean rocks must represent organi later than the most primitive forms by many million years. There is no reason to suppose that if life develo on other planets it would necessarily evolve along l similar to those that it has followed on the earth. H we enter the realm of the biologist, and it is not wi our province to discuss this matter further. Perh some day the biologist will be able to tell us exactly w life is, but until we know something more about characteristics we can only speculate on its possible fo on other planets.

Questions

1. Why do you think that the solar system probably origi from one body?
2. Give an outline of Laplace's hypothesis to explain the system.
3. From your knowledge of the motions of comets give Chapter V, why is it difficult to accept Laplace's explana What other objections are there to it?
4. What is the essential difference between the planete theory and the tidal theory?
5. If Bickerton's theory of grazing collision is accepted a explanation or a necessary part of the explanation of the ori the solar system, why do you think planetary systems must be rare in the universe?
6. Give a brief outline of some recent theories to explai origin of the planets and satellites.

ANSWERS TO QUESTIONS

In many cases it will be sufficient to refer to the pages which describe the problems under consideration.

Chapter I

1. Pp. 7–8. 2. P. 8. 3. P. 11. Rotation. 4. (*a*) The axis should be at right angles to the plane of the ecliptic; (*b*) the axis should be in the plane of the ecliptic. 5. About 3 million miles. Not very much. 6. P. 16. Refer to Fig. 2 and the explanation at the end of p. 16. 7. $66\frac{1}{2}°$ north latitude.

Chapter II

1. P. 17. 2. Notice her position with regard to the stars from night to night. It will be seen that she has a considerable movement eastward. 3. Make use of Fig. 3 and also of the model or a model similar to that suggested on pp. 19–20. The horns of the moon are the tips of the crescent and the ball representing the moon should show these tips as part of the illuminated surface. The model will show that these tips point away from the torch (the sun) if we imagine that the viewpoint is on the ball representing the earth. 4. P. 22. The chief evidence is based on occultation phenomena. 5. Pp. 23–4. 6. No.

Chapter III

1. P. 27. 2. That the outer portions of the sun are in a gaseous condition. 3. P. 29. They are responsible for the discharge of negative charges of electricity which affect our telegraphic services, etc. 4. Seven. 5. An eclipse of the sun. 6. An eclipse of the moon. 7. The most recent determination of the speed of light is 186,271 miles a second, and from these figures it is easily deduced that the times are 8 minutes 11 seconds and 8 minutes

28 seconds, respectively. 8. 21,168 days and
days, to the nearest day. 9. 2526 followed by ten

Chapter IV

1. P. 34. The velocity of escape and the high
perature are two important factors. 2. Owing t
very elliptical orbit, p. 35. 3. P. 35. 4. Carbo
oxide. Vegetable life (pp. 36–7). 5. P. 36. The
cent is seen when the planet is in various pos
between the earth and the sun, just like the moo
Venus is on the side of the sun remote from the
she appears more like the full moon. 6. Pp.
Owing to the planet's gravity being small it has pro
lost a lot of its atmosphere. Also, it is possible
most of the oxygen has been taken up by the r
7. Almost certainly natural surface markings (p
8. Probably to the oxidized rocks (p. 39). 9. Pp.
10. The rapid rotation of the planet (p. 41). 11.
ably very extensive, which adds to the apparent dia
of the planet and partly explains its low density in
parison with the earth (p. 41). 12. The spectros
shows that marsh gas and ammonia exist there and
do not support life such as we know (p. 42). 13.
14. It is the only planet which is less dense than
(p. 45). 15. Pp. 46–7. 16. Their plane is turne
wards us (p. 46). 17. P. 47. 18. Sir William Her
(pp. 47–8). 19. They move in orbits which are n
at right angles to the plane of the ecliptic (p. 48).
Life such as we know it could not exist. 21. P. 49

Chapter V

1. They are very much smaller and also many of
move in orbits which are highly inclined to the ec
(p. 51). 2. Because they are too far from Jupite
have been disrupted by him. No other planet c
have had an effect equal to that of Jupiter (p. 52).
Pp. 52–3. 4. P. 56. In the nucleus (p. 57). 5. M
of them move in orbits highly inclined to the ecli

They differ from the asteroids in the fact that many of them have retrograde motion (p. 55). 6. Light repulsion (p. 56). 7. P. 57. 8. Biela's (p. 58). 9. P. 58. 10. The intense heat caused by friction with the atmosphere produces the glow, but as the bodies are very small they are rapidly burnt up. 11. P. 59. Meteors are more common. 12. Pp. 59–60. 13. Owing to the absence of an atmosphere on the moon there are no weathering effects and hence surface features are more permanent than on the earth.

Chapter VI

1. Observations carried out over a few nights will show that a planet changes its position with reference to the stars (p. 61). 2. The base line is too small for their great distances (p. 62). 3. P. 63. 4. P. 65. 5. P. 68. 6. They differ chiefly in their densities (see pp. 66–7). 7. P. 69. 8. (*a*) Extermination through intense cold or extreme heat, or it will become extinct for reasons not well known, like many other species; (*b*) extermination through one of the first two conditions. 9. They are so far away that their movements cannot be detected except by the most delicate instruments; hence they are called "fixed stars," and are fixed in so far as we cannot see their movements (p. 62). 10. Nearly 16 times as bright (see pp. 64–5 for method of computation).

Chapter VII

1. The former lie nearly in our line of sight but have no physical connection; the latter are revolving around their common centre of gravity (p. 71). 2. No. 3. The mass of the binary system can be found (p. 72). 4. Algol. 5. P. 73. 6. Pp. 74–5. 7. Pp. 75–6. The first theory described is known as the Pulsation Theory; the second is the Theory of Rotational Instability. 8. Its sudden and very great increase in brightness (pp. 76–7). 9. P. 77. The heavenly bodies are too far apart for a sufficient number of collisions to occur to account for all the novae.

Chapter VIII

1. It should be observed at different times of the y and its appearances recorded. Obscuring matter space cuts off the light in places. 2. Like a bun (p. Its appearance would depend upon their positions. some it would look like a spiral nebula, but to other different positions no sign of the spiral structure wo be seen (p. 83). 3. P. 80. 4. P. 81. 5. A disc rota as a solid body, but each star in the Milky Way has own time of revolution round the centre of gravity the whole system. 6. Cosmic dust. It is possi (p. 82). 7. Over 13,000 miles a second (see p. 84 the method of computation). 8. P. 83. 9. P. 84. T extra galactic nebulae. 10. The spectroscope. It is a used to determine line-of-sight velocities of distant st or nebulae (p. 86). 11. P. 87.

Chapter IX

1. Owing to certain orderly arrangements in the so system (p. 89). 2. Pp. 89–90. 3. The theory wo require that the comets, like the planets, should ha direct motion, but about half the comets possess ret grade motion. For other objections see pp. 90- 4. The planetesimal theory postulated ejection of mat through eruptions of the sun combined with tidal effe produced by an approaching star, whereas the ti theory suggested that tidal action alone sufficed to cau the ejection of matter. In addition, according to t planetesimal theory, an enormous number of tiny plan were formed by the ejection, and local condensatio swept these up in time, so that they slowly grew in planets. The tidal theory required the formation of t planets quickly from matter which was ejected by t sun. 5. Because of the extreme improbability of col sions taking place. 6. See pp. 94–5.

AND THEIR DENSITIES AND MASSES

	Diameter in Miles.	Density when Water is the Unit.	Mass when the Earth's Mass is the Unit.	Mean Distance from the Sun in Millions of Miles.	Sidereal Period, or Length of Planet's Year in Years
Sun	864,000	1·41	333,434	—	—
Moon	2,160	3·34	0·0123	—	—
Mercury	3,000	3·73	0·037	36·0	0·241
Venus	7,600	5·21	0·826	67·3	0·615
Earth	[1]7,927, [2]7,900	5·52	1·000	93·0	1·000
Mars	4,200	3·94	0·108	141·7	1·881
Jupiter	[1]88,700, [2]82,800	1·34	318·4	483·9	11·862
Saturn	[1]75,100, [2]67,200	0·69	95·2	887·1	29·458
Uranus	30,900	1·36	14·6	1785	84·015
Neptune	33,000	1·32	17·3	2797	164·788
Pluto	?	?	?	3670	247·697

1 and 2 refer to the equatorial and polar diameters, respectively (see pp. 7, 41, and 45).

The computations of the distances of the planets are based on the assumption that the mean distance of the earth from the sun is 93,003,000 miles. This is in accordance with the recent determination of the solar parallax by the Astronomer Royal. As earlier results were based on a mean distance of 92,900,000 miles, there are very slight discrepancies between the figures given above and those found in the text.

The mass of the earth is nearly 6×10^{21} tons, and the mass of any of the other bodies can be found by multiplying this by the figures given in the fourth column. In the case of Pluto, only its distance from the sun and its sidereal period are known with certainty.

NOTES FOR OBSERVERS

AMATEUR astronomers have frequently felt disappoir because their work has seemed fruitless, and in many ca they have given up the study of a subject which had onc great attraction for them. This happens especially v those who work in isolation and have few with whom t can share their interests. Those who intend taking astronomy seriously are strongly recommended to join sc society or association which makes a speciality of the subj The best Association for amateurs is The British Astronom Association, which does very valuable work and is alw ready, through the Directors of its various Sections, to o advice to its new members. It holds about nine meeting year and issues a *Journal* which provides an account of e meeting and contains a number of papers contributed by members. By joining such an Association it is possible keep abreast of the times in astronomical development (a the developments in astronomy are both extensive and rap Full particulars can be obtained from the Assistant Secreta 303 Bath Road, Hounslow West, Middlesex. There are fo teen Sections devoted to specialized work in astronomy, Sun, the Moon, Jupiter, Saturn, Mars, Mercury and Ven Comets, Meteors, etc., so a member has a wide choice subjects. Of course there is no obligation to join any p ticular section; nor is this necessary, because the *Journ* supply the most recent information in astronomical c coveries. The Library contains a fine collection of wo on astronomy, and members can borrow the most up-to-d books, which keep them well informed in all branches of subject.

Star charts are essential if a working knowledge of constellations and stars is required. A selection of one fr the following short list will suffice at first for the beginner

Philip's Chart of the Stars, by E. O. Tancock.
Sign Posts to the Stars, by F. E. Butler.
The Stars at a Glance.
Published by George Philip, Fleet St., E.C. 4.

Gall's Easy Guide to the Constellations.
The People's Atlas of the Stars.
Published by Gall & Inglis, Henrietta St., W.C. 2.

Guide to the Stars, by H. Macpherson.
Thomas Nelson & Sons, Parkside, Edinburgh.

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